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(54) **SPINDLE MODULE, PICK-AND-PLACE MACHINE AND METHOD OF ASSEMBLY**

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CPC H05K 13/0406; H05K 13/0411; H05K 13/0409
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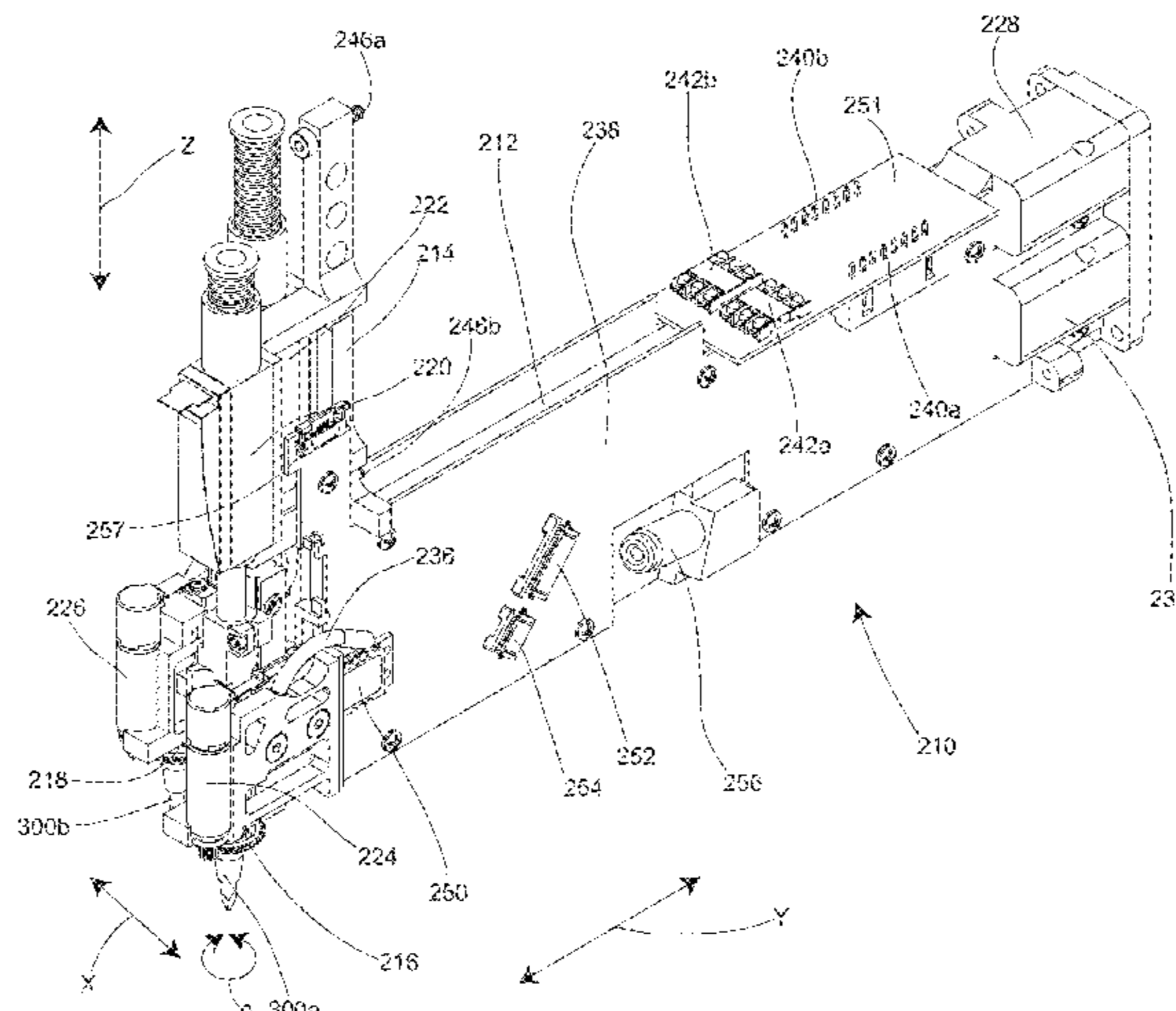
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(57) **ABSTRACT**

A method of assembly comprising a pick-and-place spindle module having a modular body structure including a first receiving location configured to receive a spindle, a first z-axis motor configured to move a spindle received in the first receiving location in a z-axis, a first theta motor configured to rotate a spindle received in the receiving location, an air distribution system including an air distribution port, the air distribution system configured to deliver received air from the air distribution port to a spindle received in the first receiving location, an electrical distribution system including an electrical distribution port, and a mechanical attachment mechanism, the mechanical attachment mechanism configured to facilitate attachment of the modular body structure to a spindle bank such that the air distribution port is connected to receive air from the spindle bank and the electrical distribution port is configured to receive electricity from the spindle bank.

8 Claims, 17 Drawing Sheets



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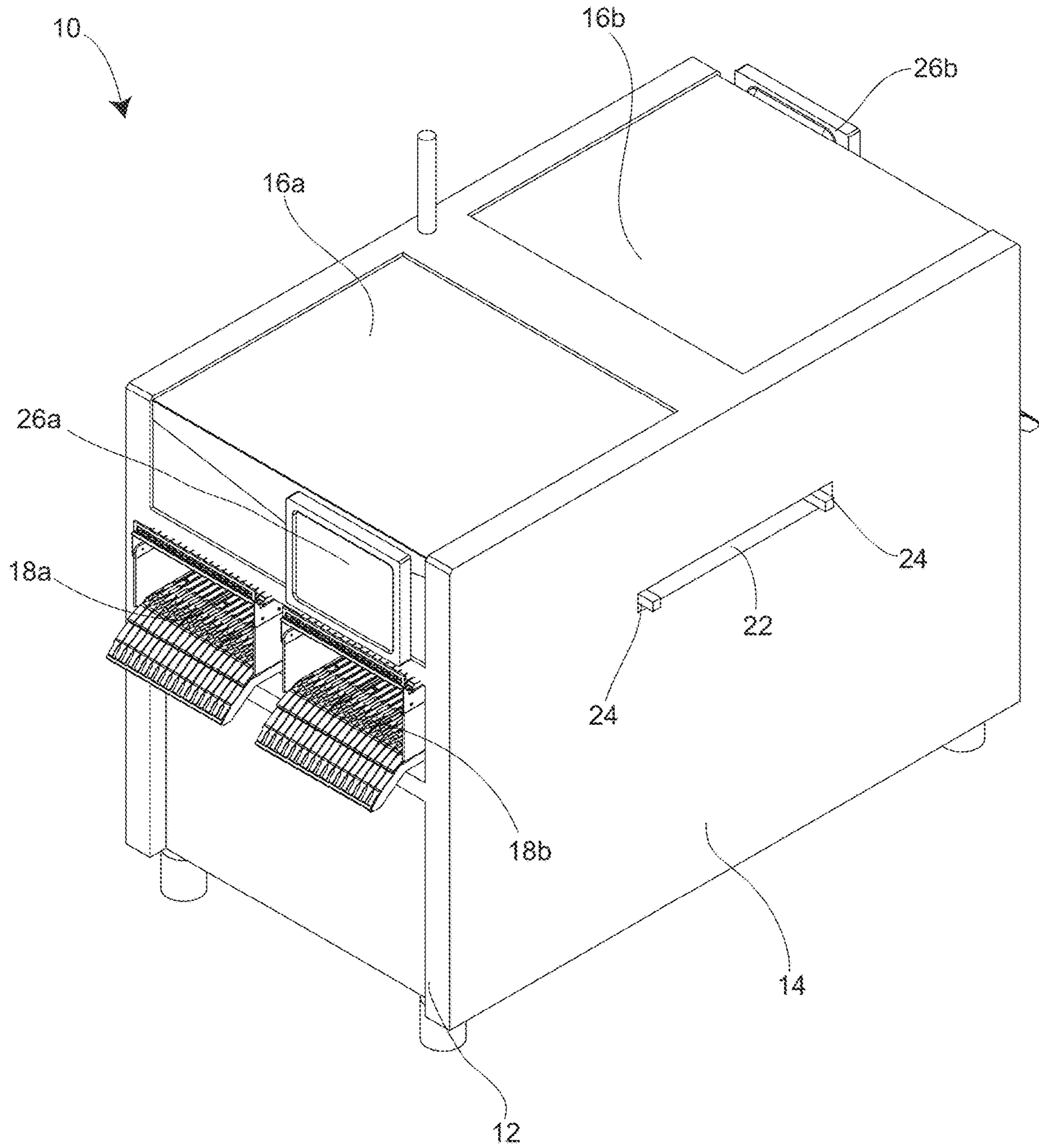


FIG. 1

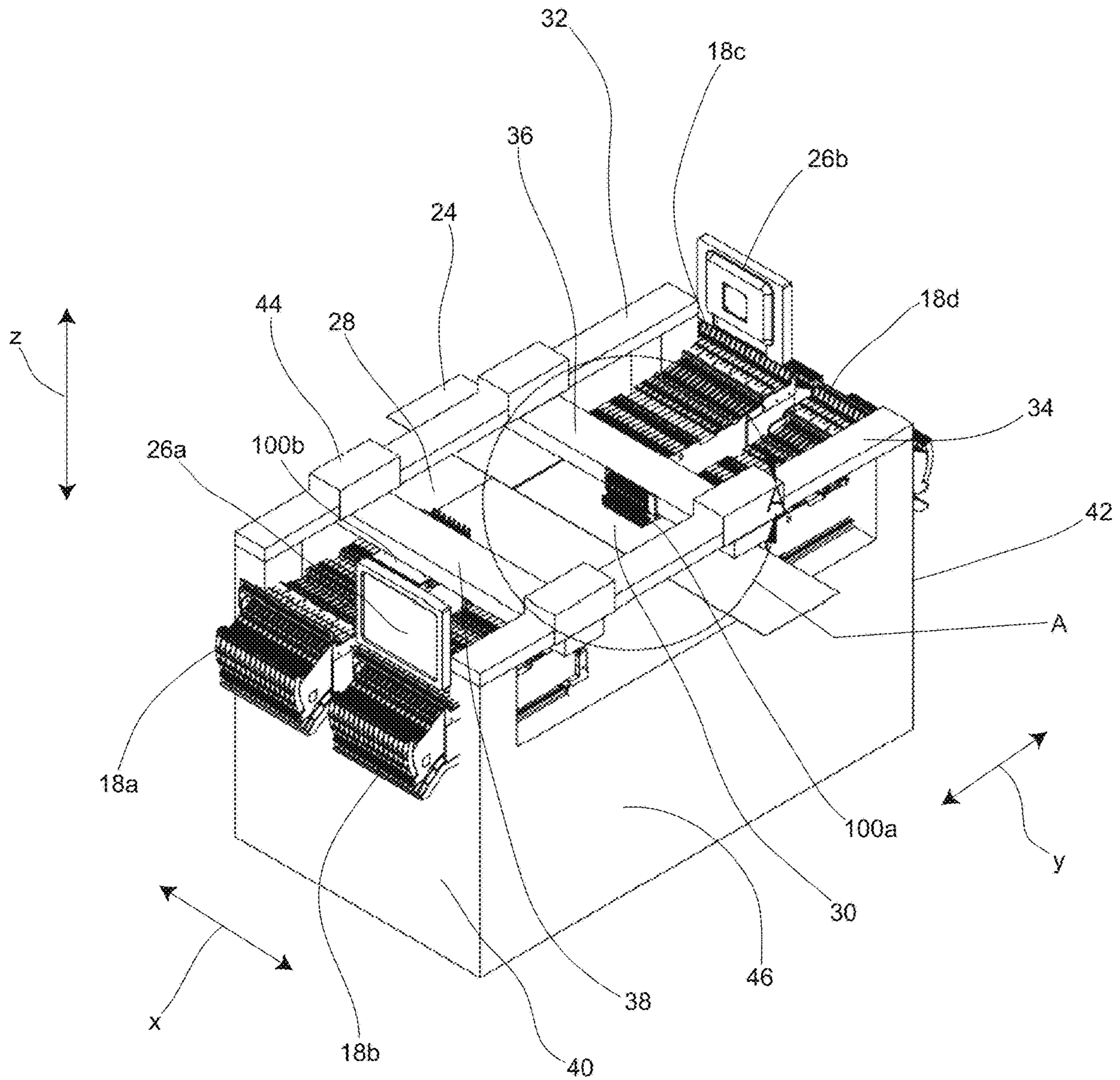


FIG. 2A

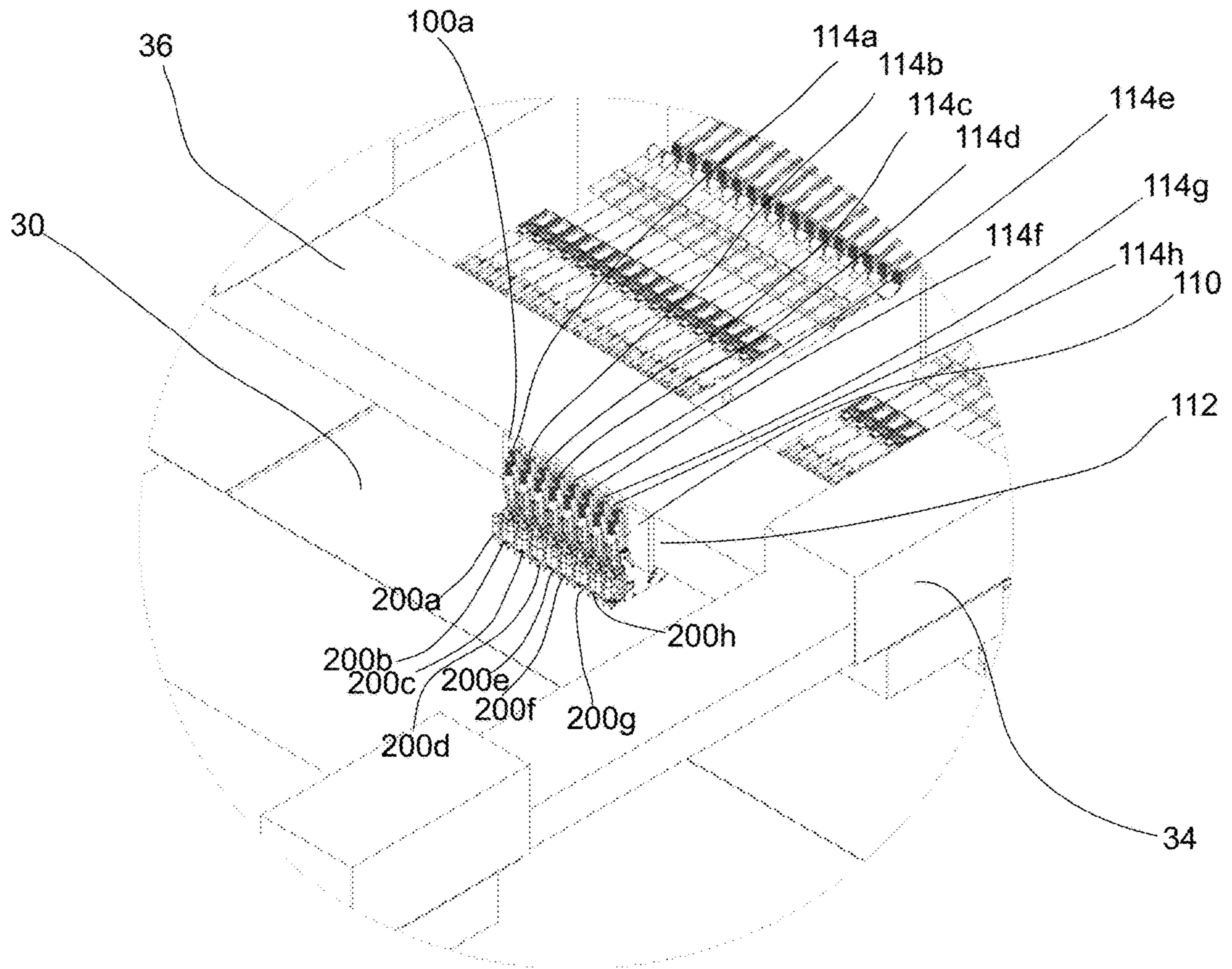
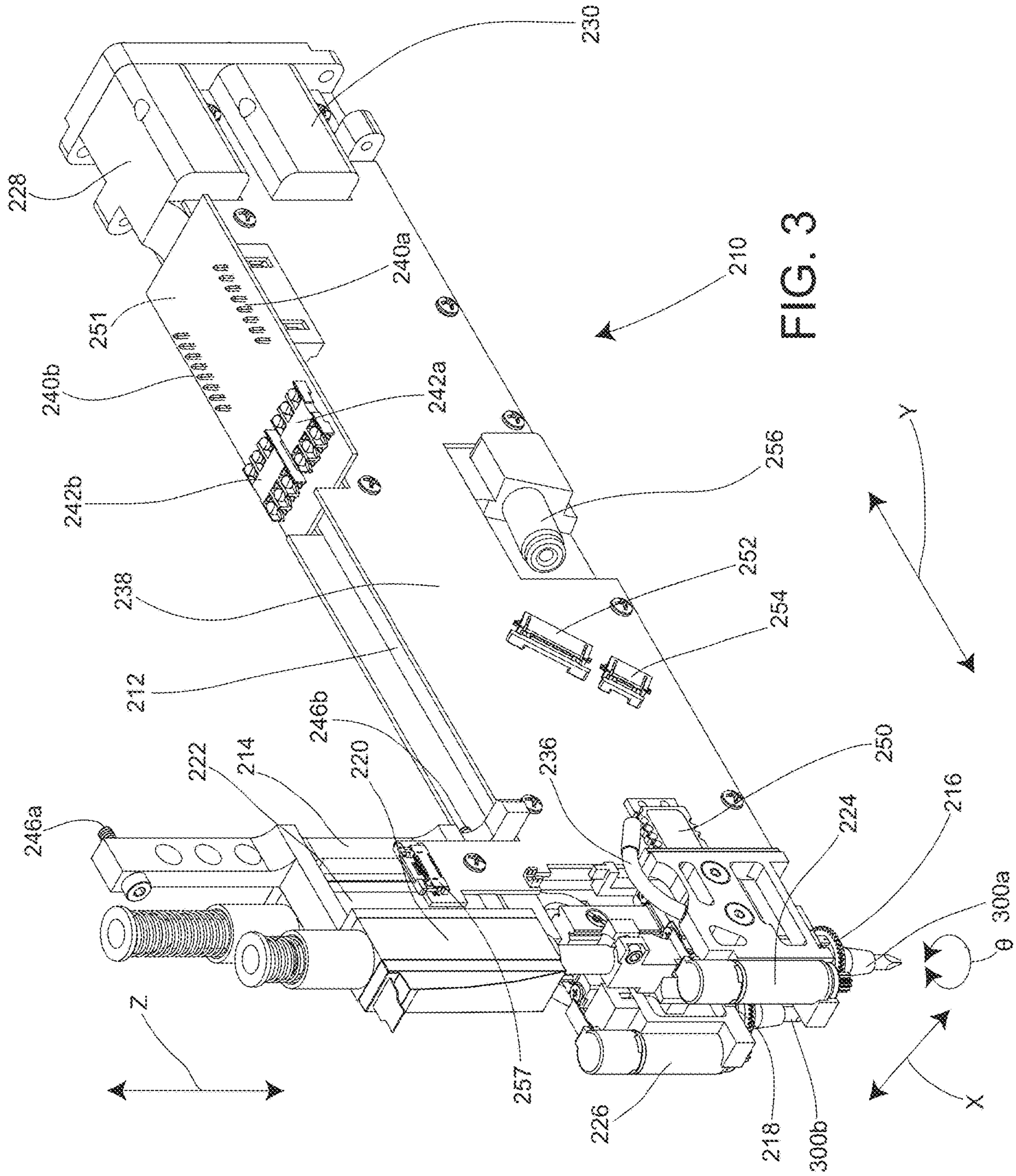


FIG. 2B



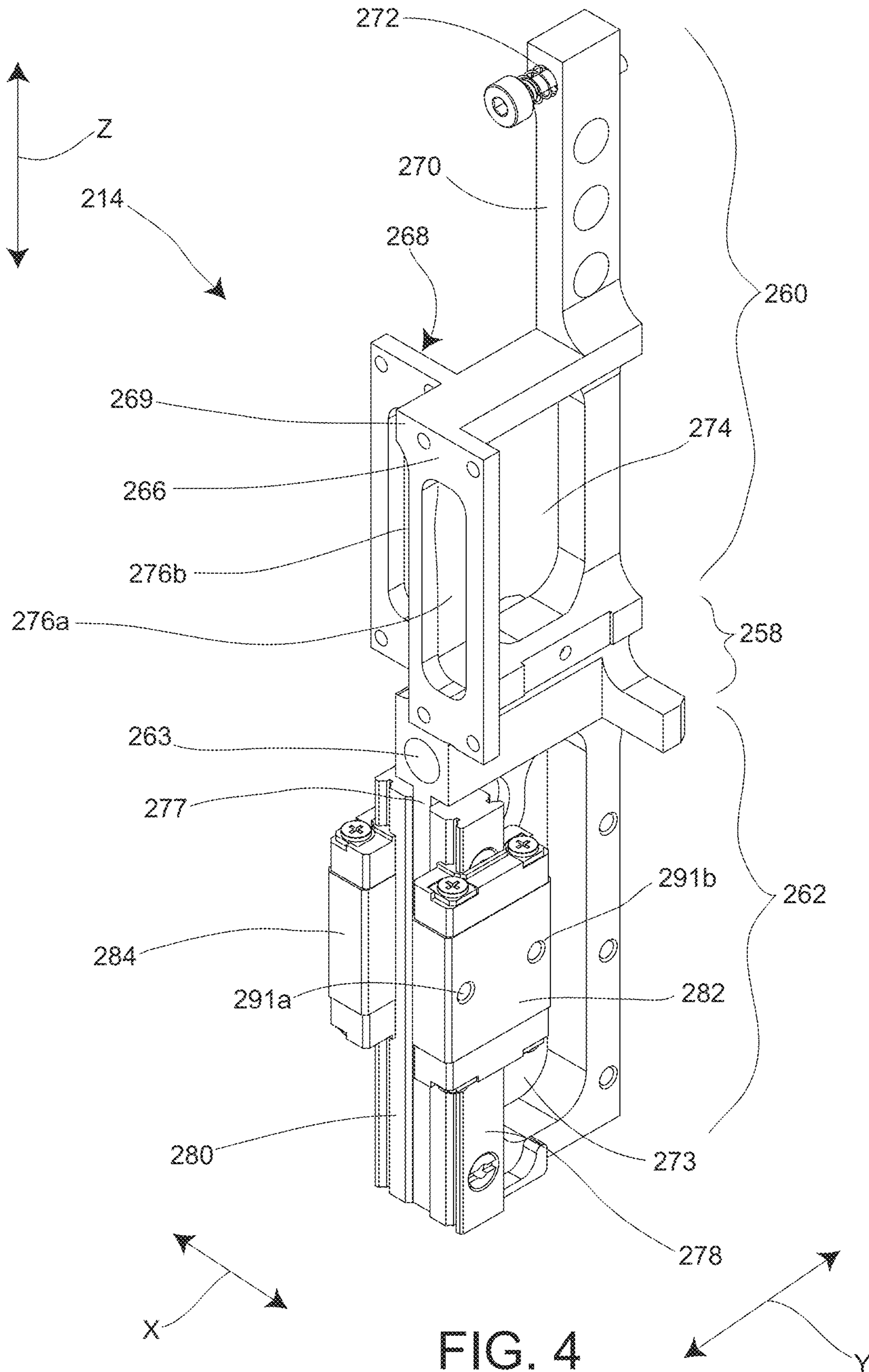


FIG. 4

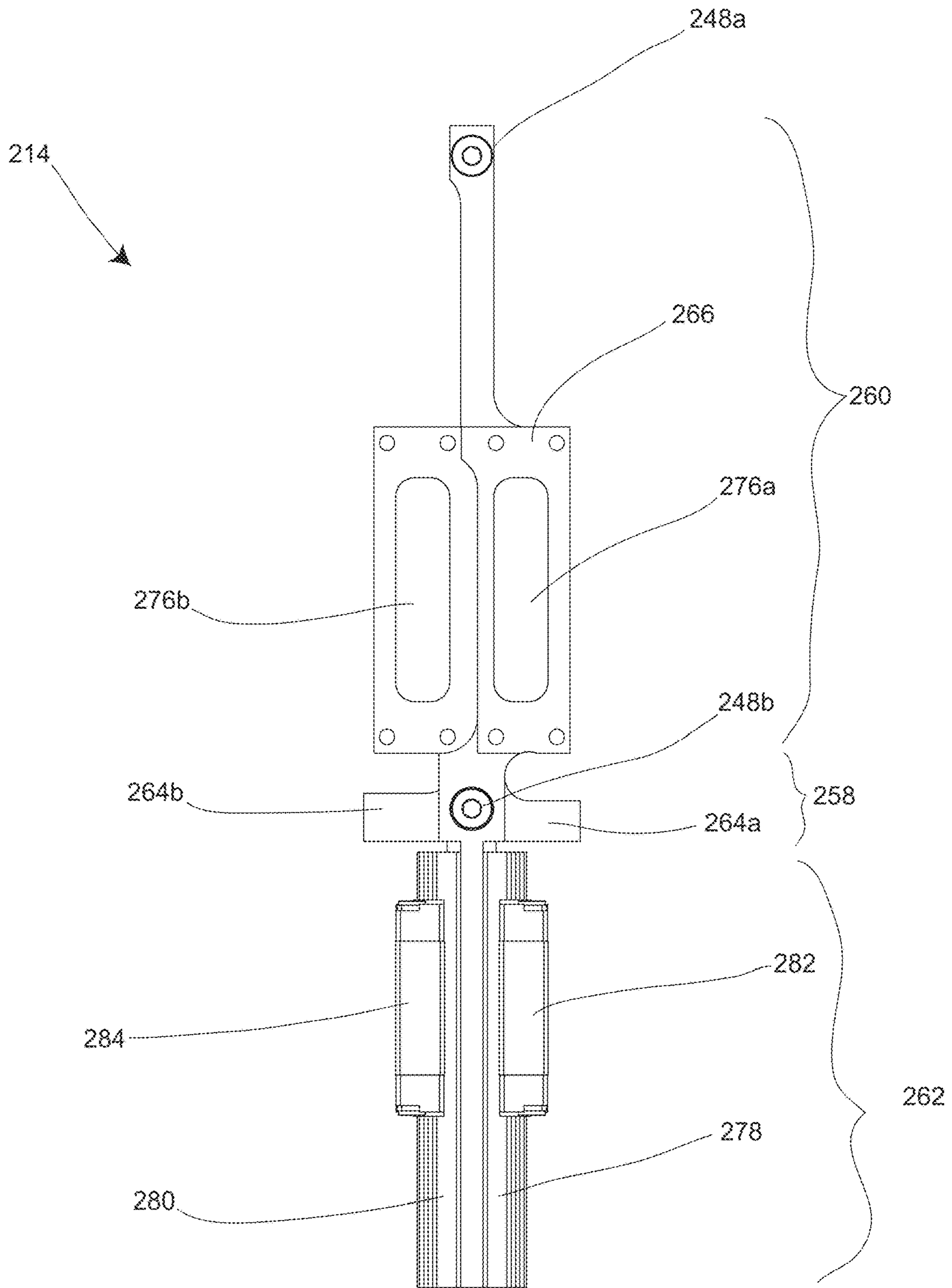


FIG. 5

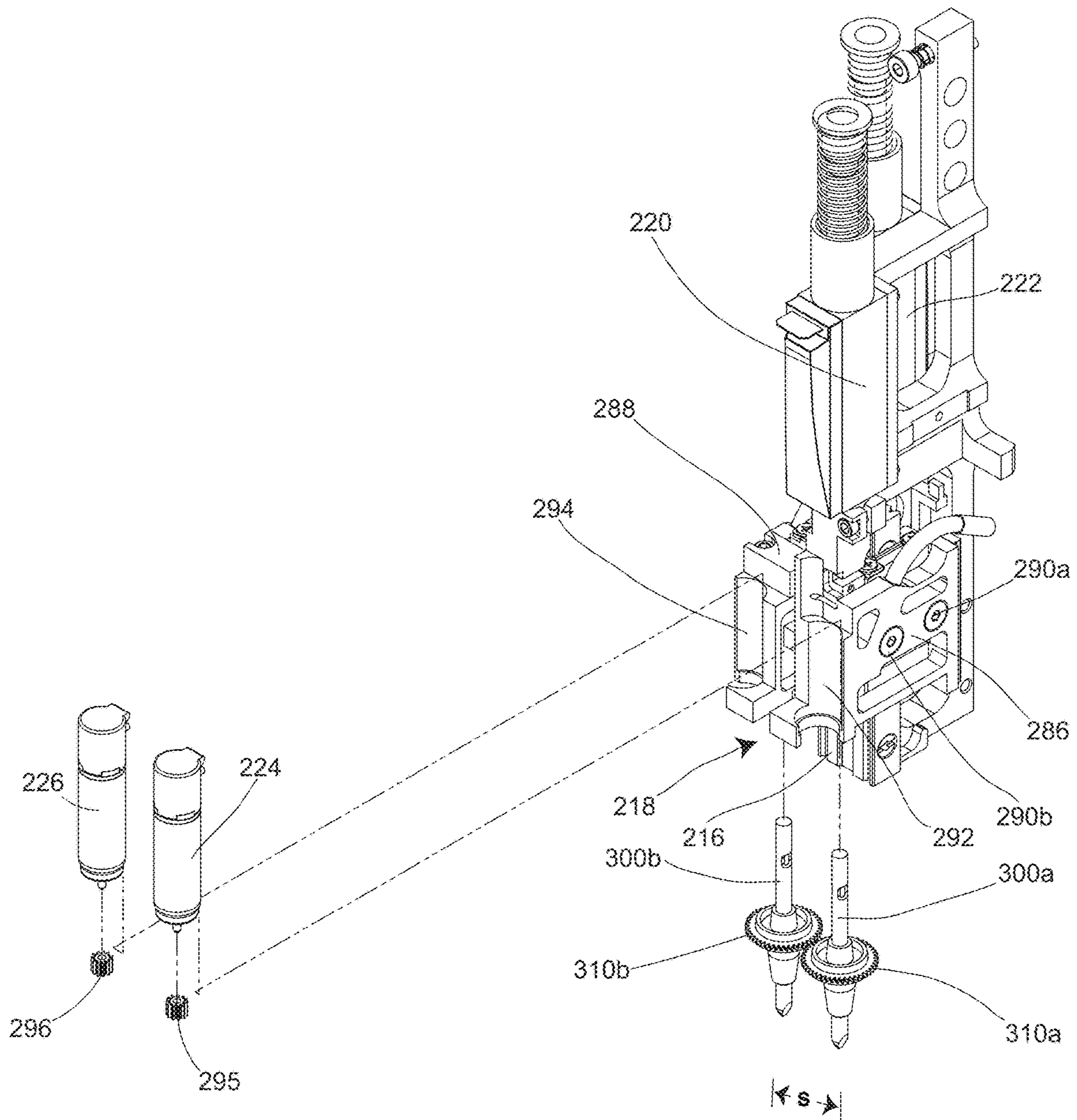


FIG. 6

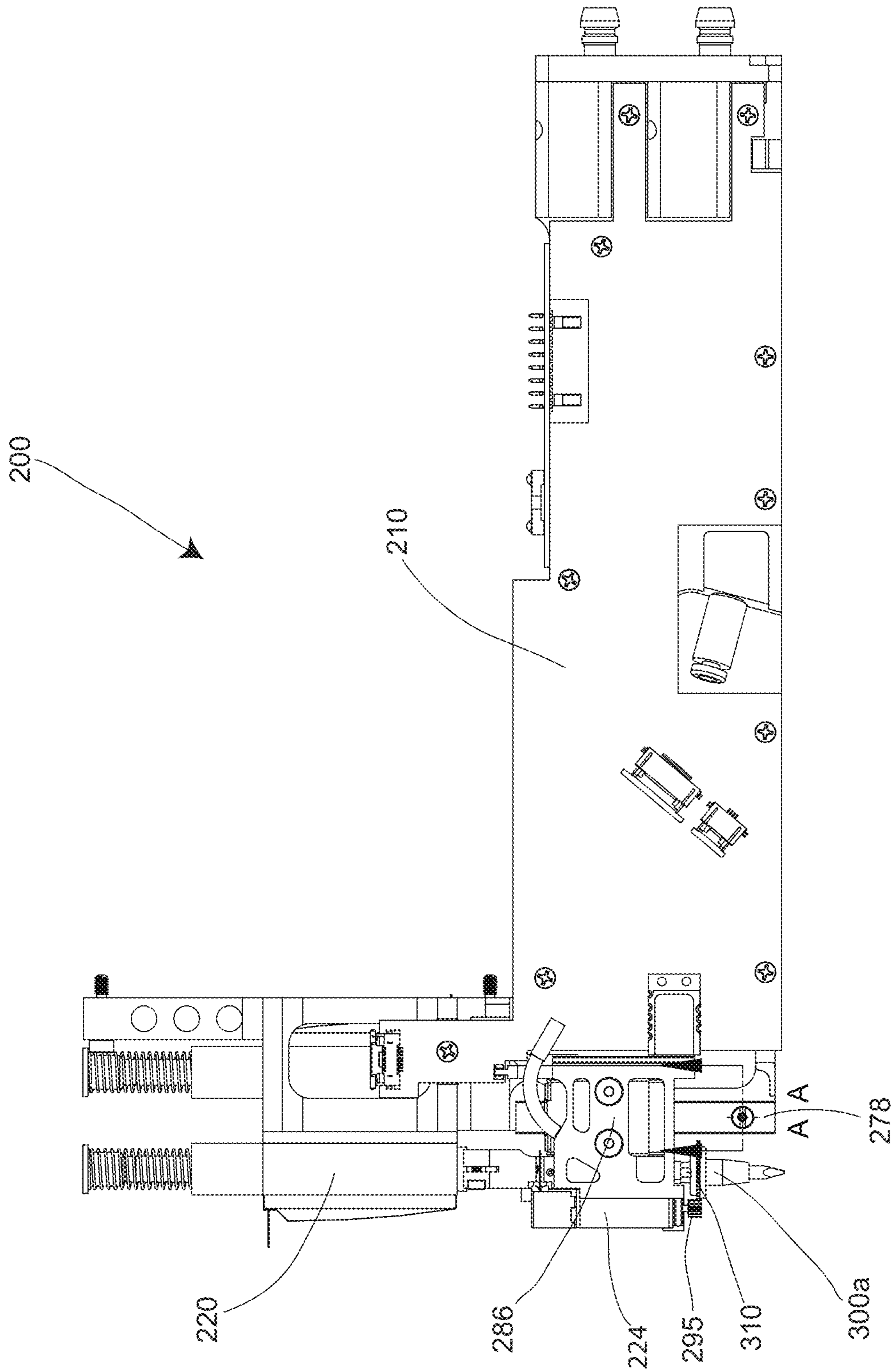


FIG. 7A

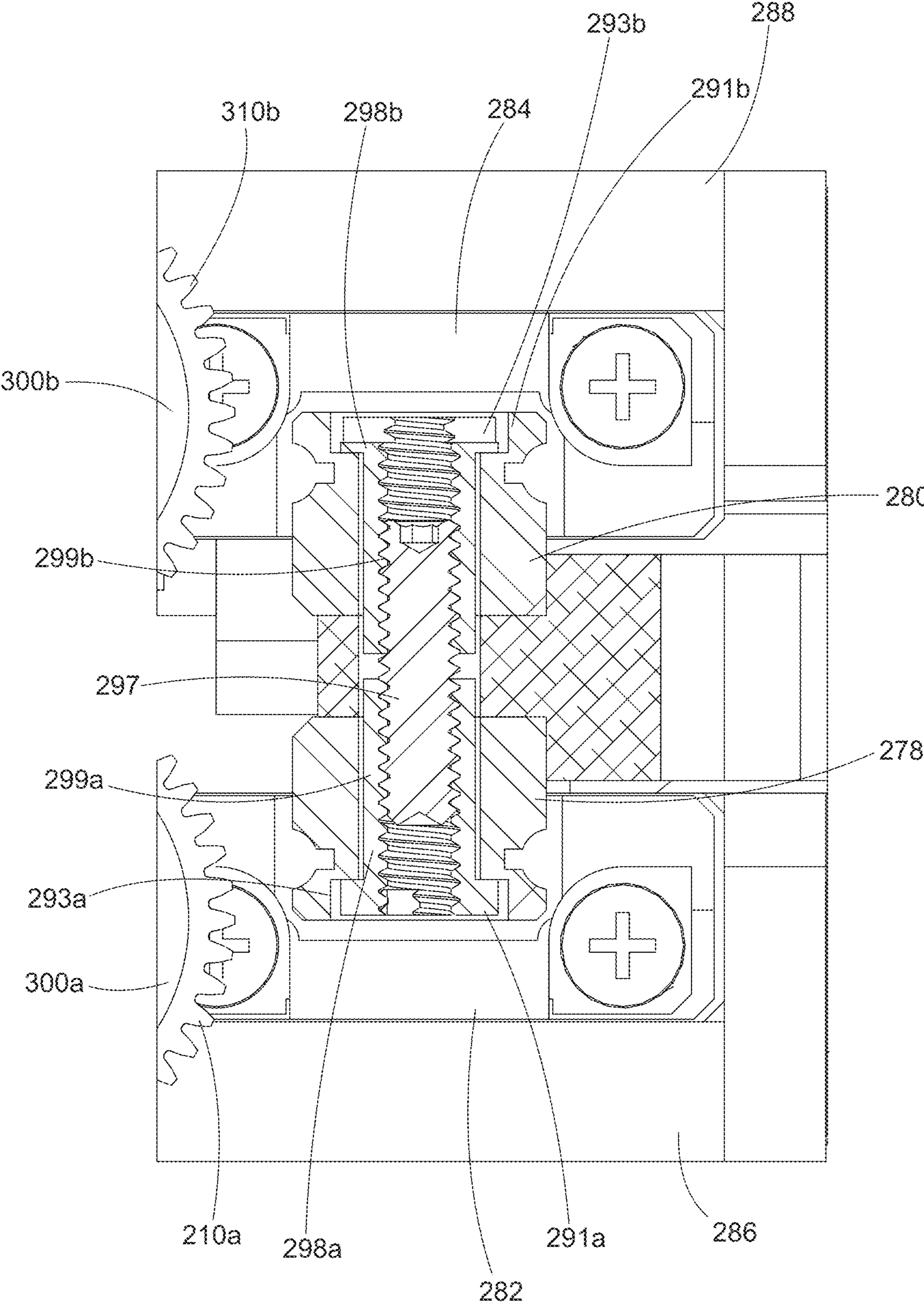


FIG. 7B

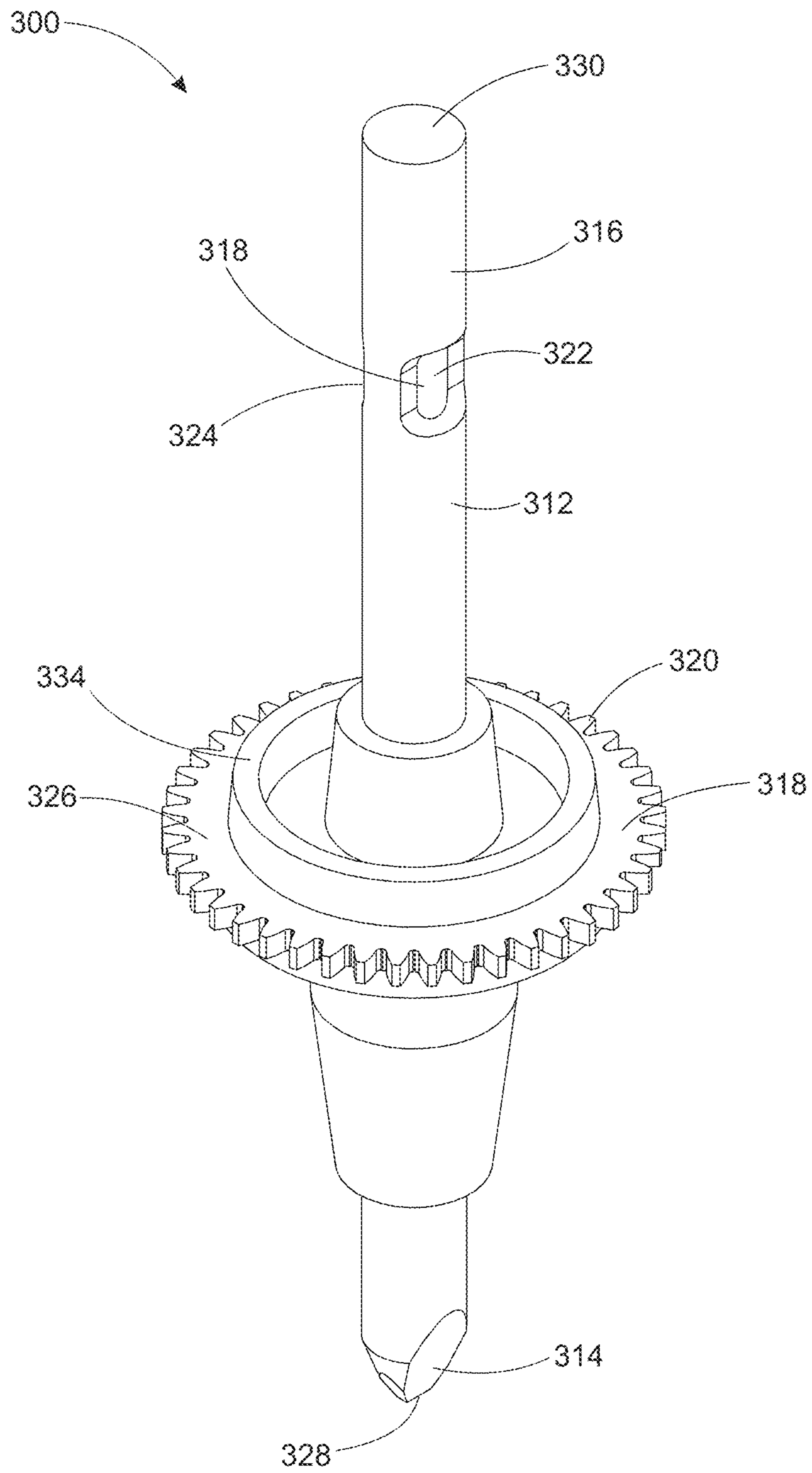


FIG. 8

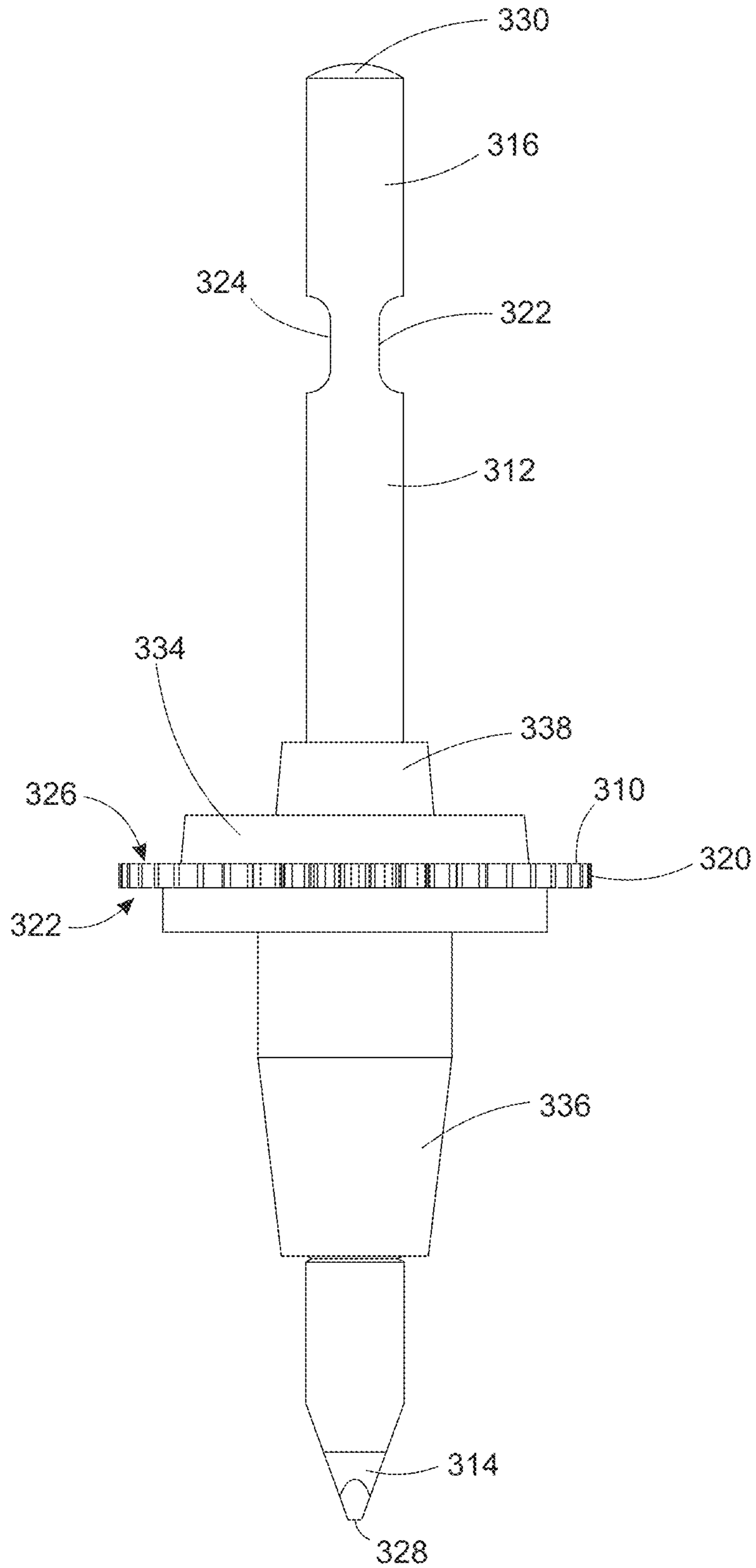


FIG. 9

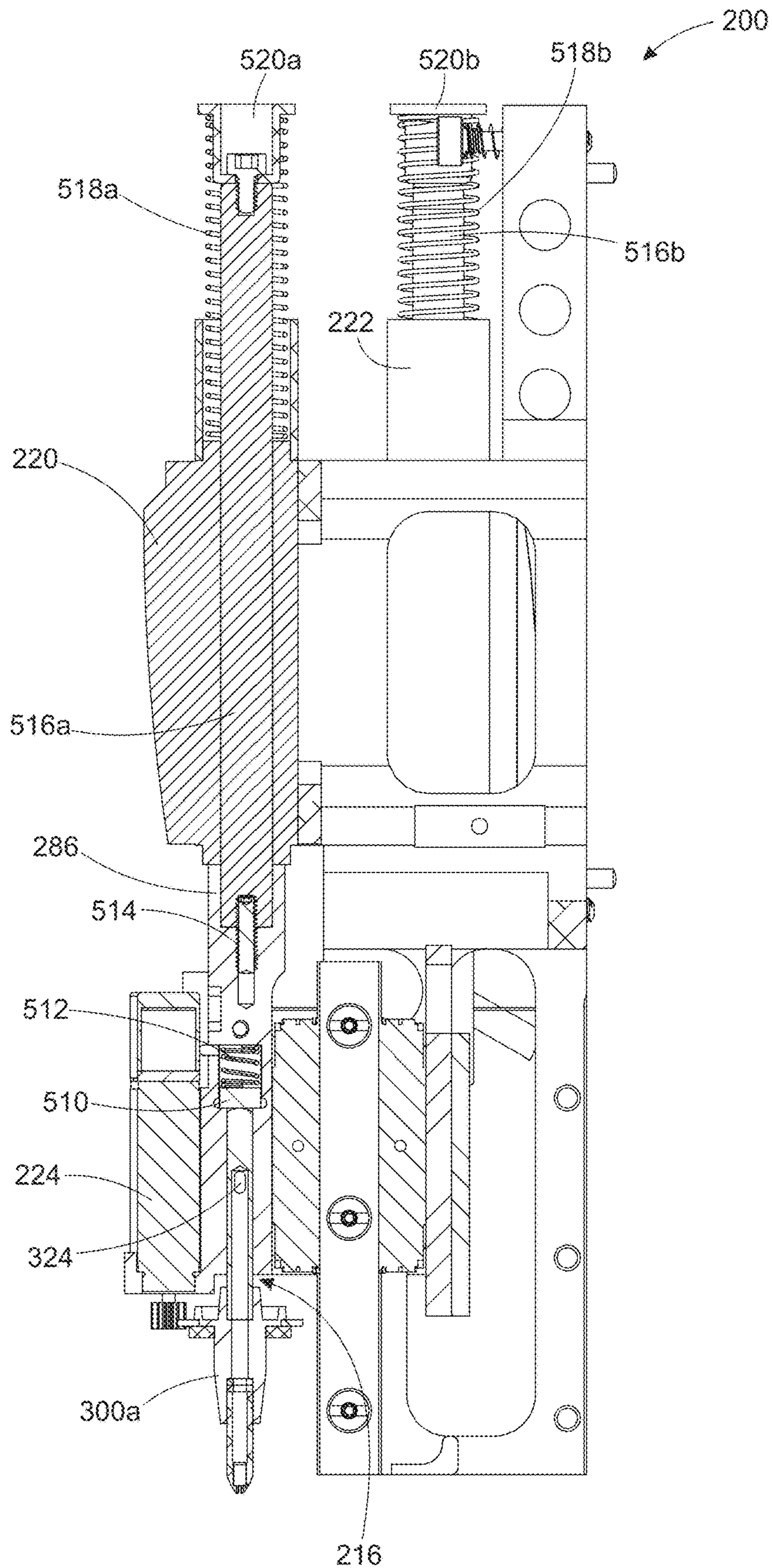


FIG. 10

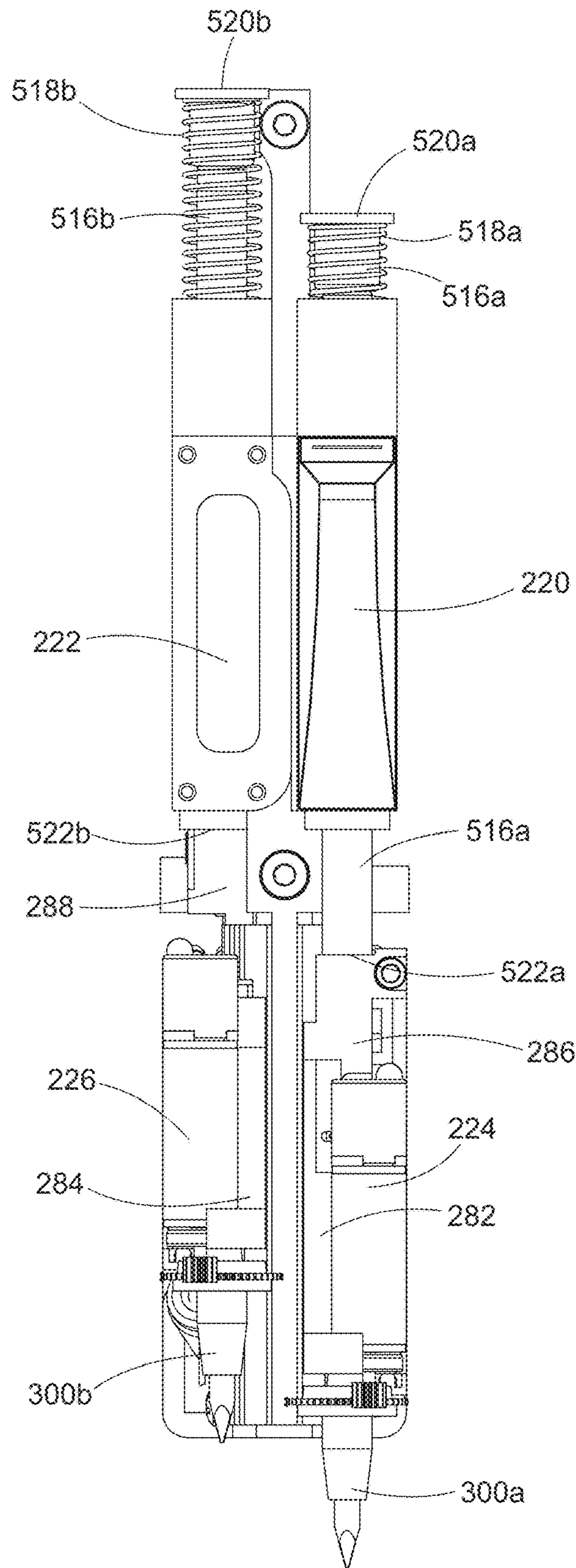


FIG. 11

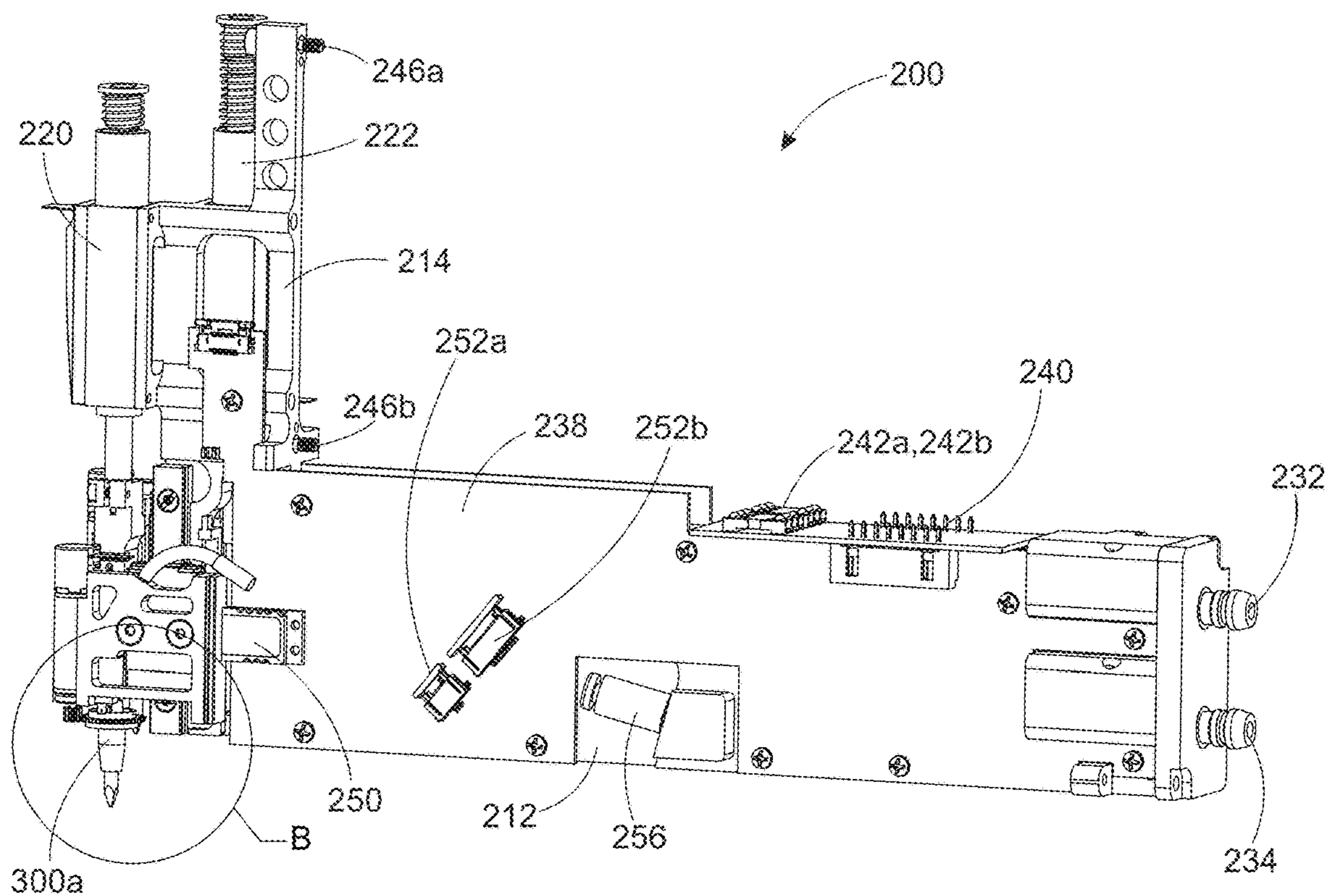


FIG. 12A

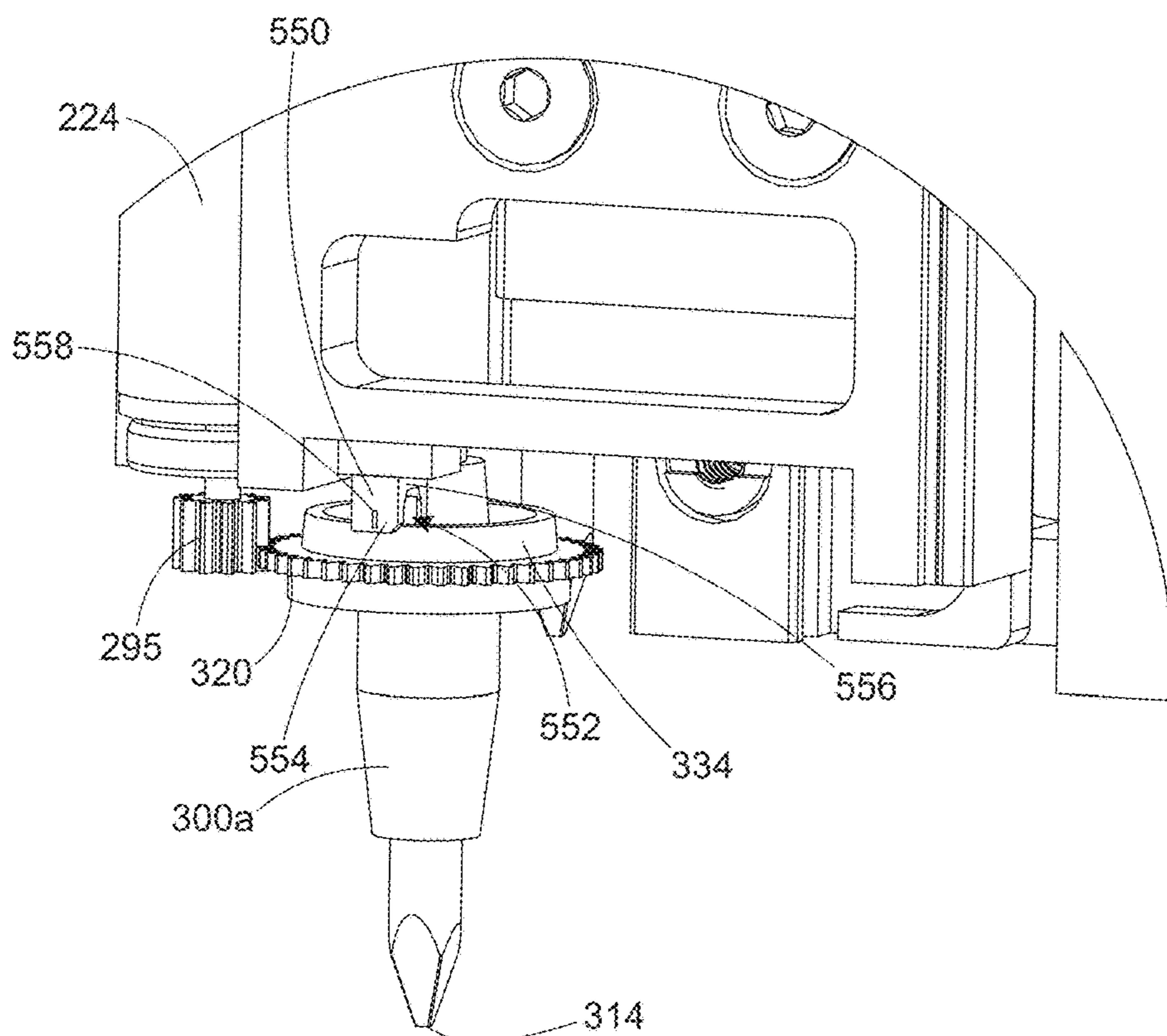
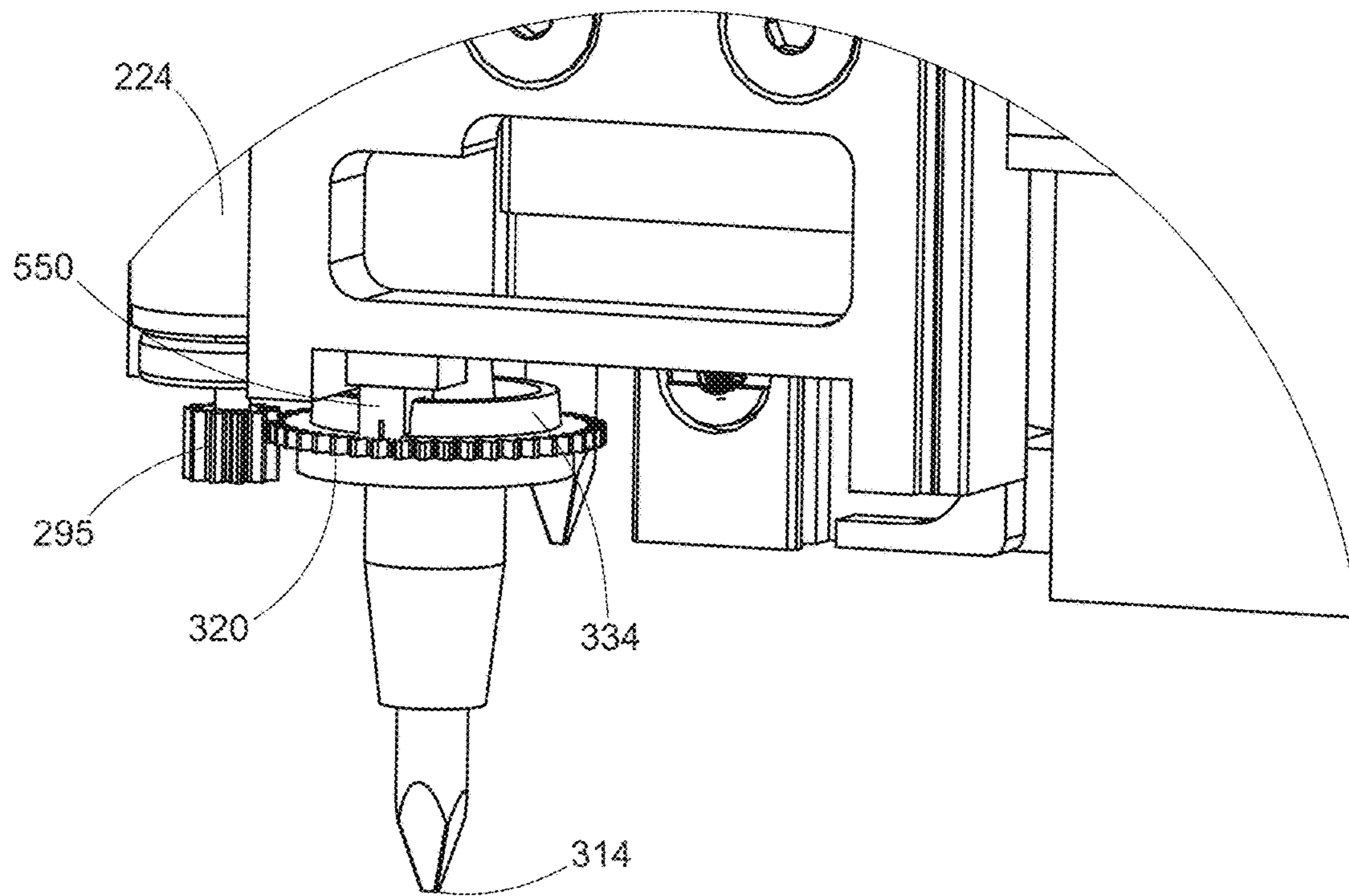
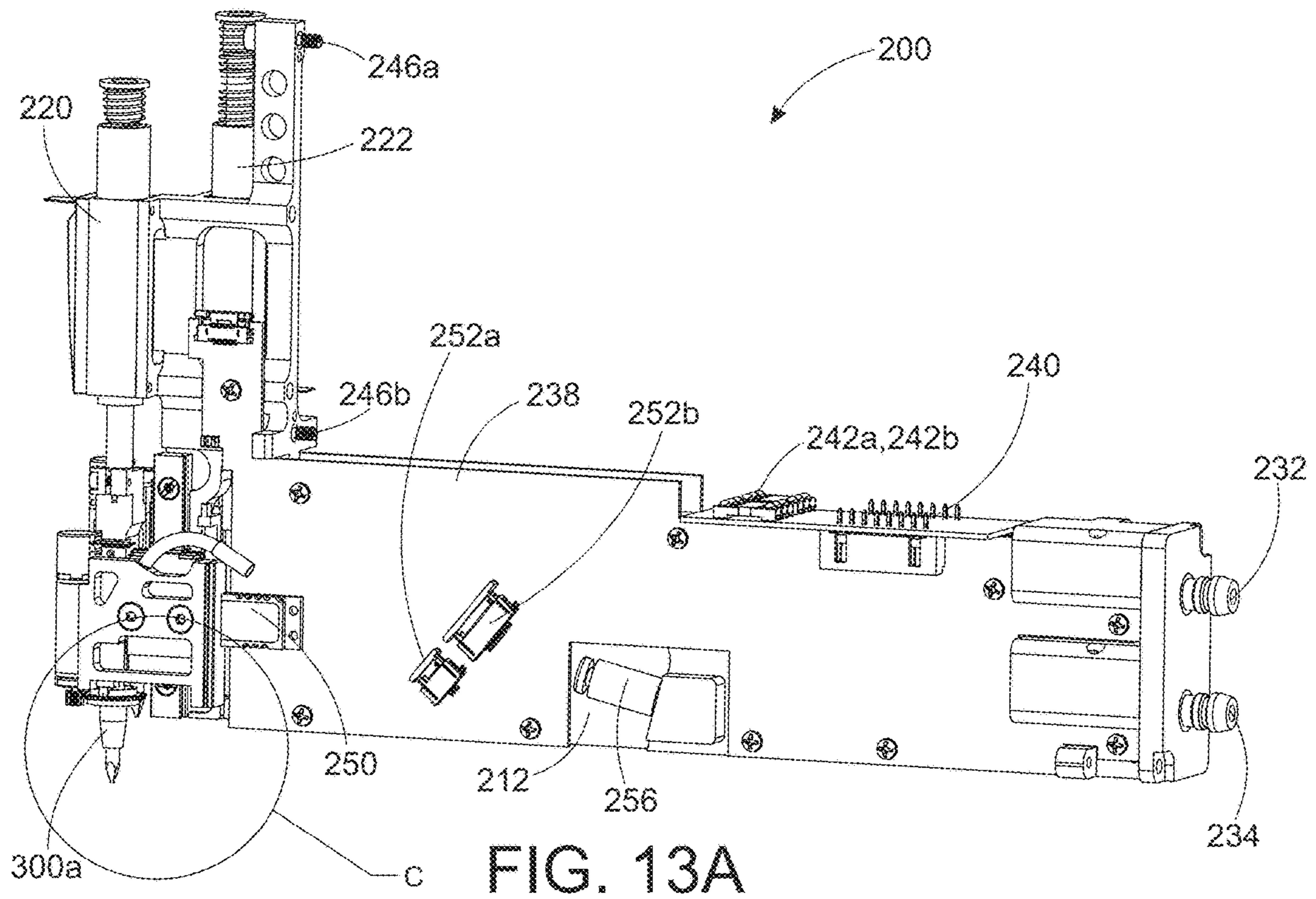


FIG. 12B



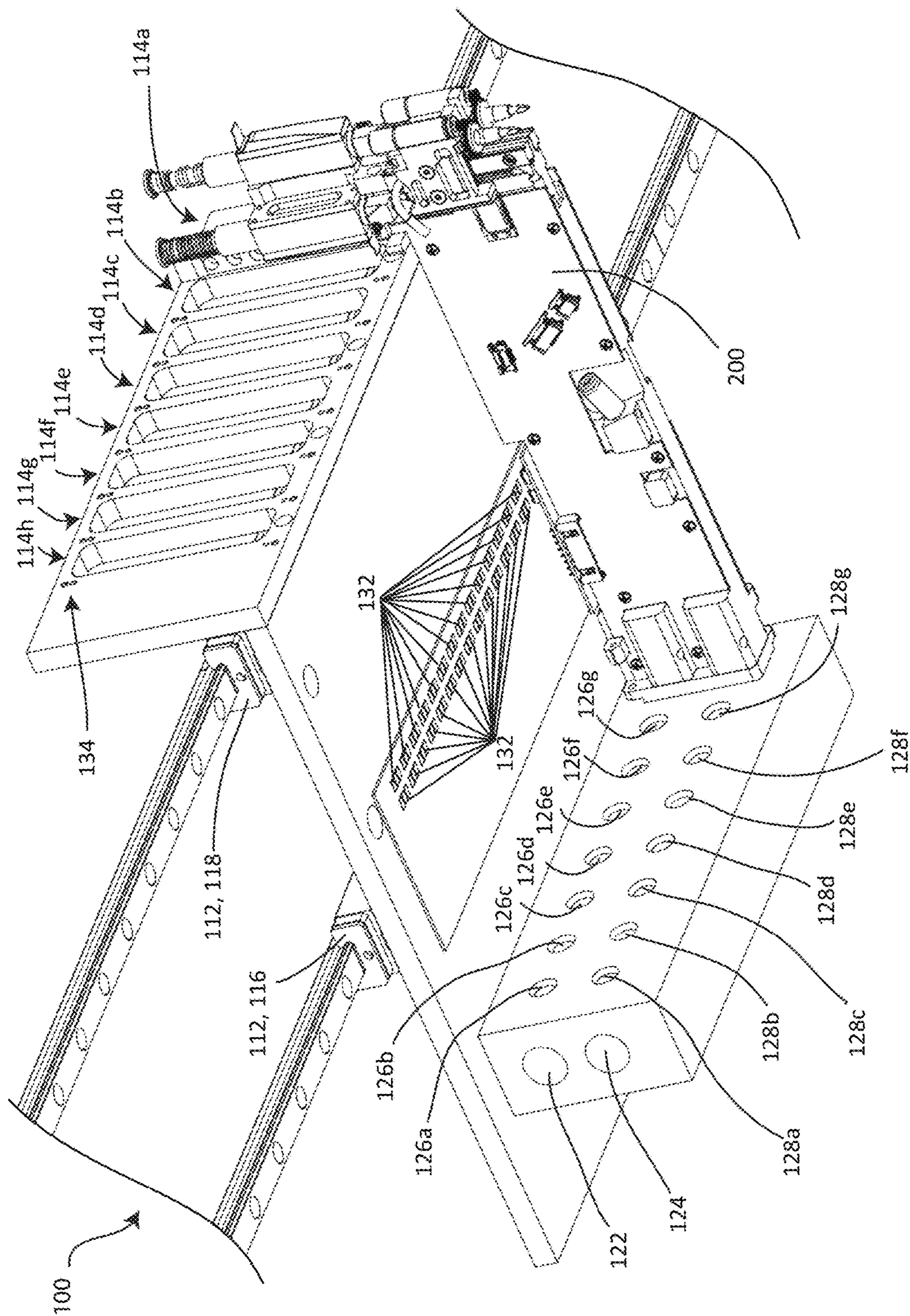


FIG. 14

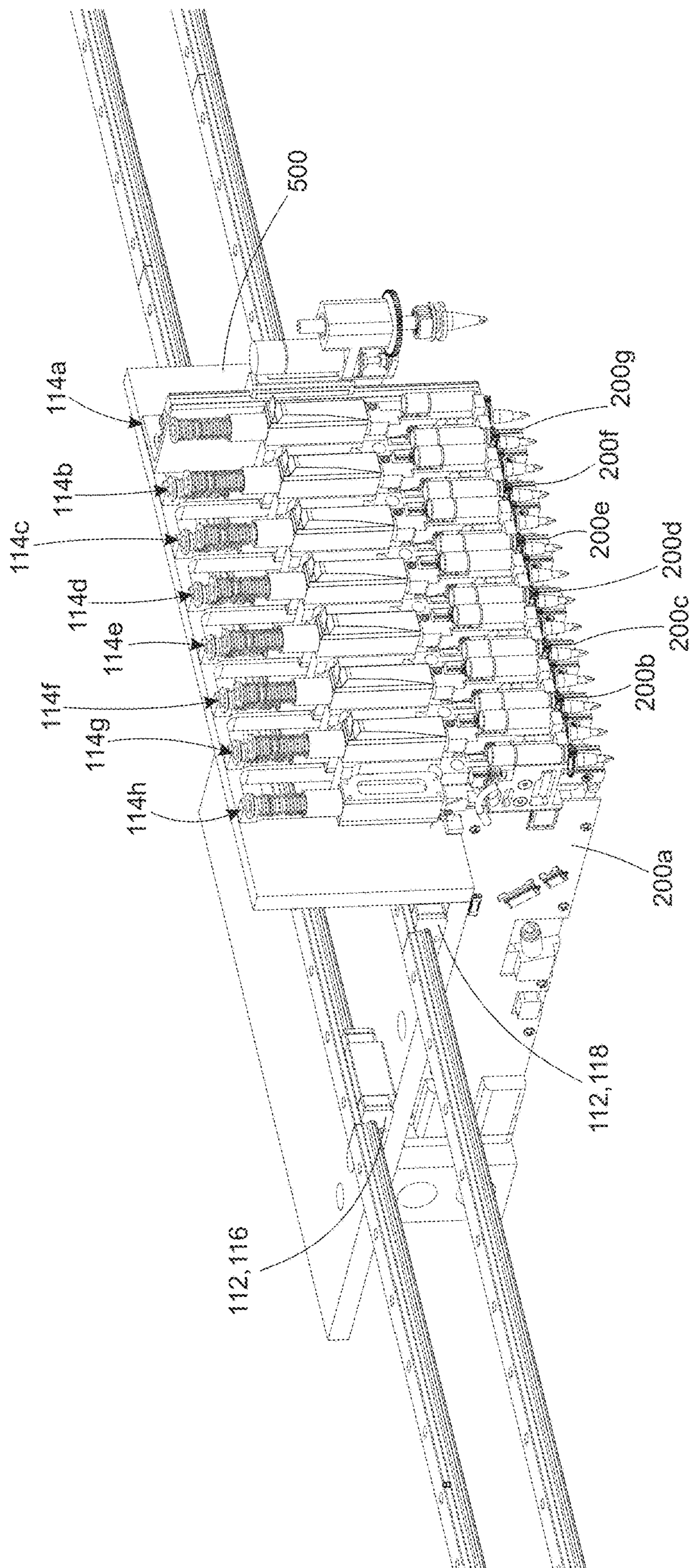


FIG. 15

SPINDLE MODULE, PICK-AND-PLACE MACHINE AND METHOD OF ASSEMBLY

RELATED APPLICATIONS

This application claims priority to U.S. patent application Ser. No. 16/969,751, filed Aug. 13, 2020, entitled “Dispensing Head, Nozzle and Method,” which claims priority to International Patent Application No. PCT/US2018/019753, filed Feb. 26, 2018, entitled “Dispensing Head, Nozzle and Method,” the disclosures of which are hereby incorporated by reference to the extent that is it not inconsistent with the present disclosure.

BACKGROUND

Assembly machines include complex robots that have dispensing heads that move along one or more axis to assemble an unfinished product. Dispensing heads may be capable of picking, placing, providing material to a component or surface, manipulating, screwing, or otherwise dispensing of a task or material. In pick-and-place assembly machines, for example, dispensing heads are often configured to receive multiple different spindle and nozzle assemblies in order to pick, place, and assemble various different parts efficiently. Dispensing heads must often include a spindle assembly for creating rotation in a nozzle, along with the ability to move the nozzle in the Z-axis. As a result of these requirements, dispensing heads for pick-and-place machines are often heavy and have a large volume.

Further, assembly machines may include multi-spindle or multi-nozzle dispensing heads. These dispensing heads may be configured to, for example, pick up multiple components from one or more feeder banks, and then move to a placement location to place the multiple components. This reduces assembly time compared to having a single spindle or single nozzle. This is because single spindle and nozzle arrangements will typically require the back and forth movement between the feeder banks and the placement location with each placed component. However, with additional spindles and nozzle receivers located on a dispensing head, the size, volume and engineering complexity of the head is often increased. Further, if one spindle or nozzle breaks or begins functioning improperly, the entire dispensing head may be compromised until such a problem is fixed.

Moreover, present dispensing heads for pick-and-place systems are typically controlled by machine level processors or control systems. These systems preclude the creation of an independent motion control profile for each individual spindle on a multi-spindle dispensing head. Rather, motion control profiles are created on a dispensing head level.

Thus, improved assembly machines, dispensing heads, spindles, spindle mounting modules and spindle banks to alleviate or reduce one or more of the above limitations would be well received in the art.

BRIEF DESCRIPTION

According to one embodiment, a spindle for a pick-and-place machine comprises: a shaft including a length extending between a first end and a second end, the shaft including an outer body and a hollow interior; a nozzle tip disposed at the first end of the shaft, the nozzle tip configured to contact an electronic component for manipulation of the electronic component; and a theta gear disposed on the shaft, the theta gear configured to engage with a motor of a pick-and-place

head, wherein the spindle is configured to be removably attachable from the pick-and-place head.

According to another embodiment, a method of assembly comprises: providing a pick-and-place machine having a pick-and-place head; providing a spindle for the pick-and-place machine, the spindle including: a shaft including a length extending between a first end and a second end, the shaft including an outer body and a hollow interior; a nozzle tip disposed at the first end of the shaft; a theta gear disposed on the shaft; attaching the spindle to the pick-and-place head of the pick-and-place machine; engaging, by the theta gear, with a motor of the pick-and-place head; contacting, by the spindle, an electrical component; manipulating, by the spindle, the electrical component; and removing the spindle from the pick-and-place head of the pick-and-place machine.

According to another embodiment, a dispensing head comprises: a body structure including a receiving location; a z-axis motor; a theta motor; a spindle received in the receiving location, the spindle comprising: a shaft including a length extending between a first end and a second end, the shaft including an outer body and a hollow interior; a nozzle tip disposed at the first end of the shaft, the nozzle tip configured to contact an electronic component for manipulation of the electronic component; and a theta gear disposed on the shaft, the theta gear configured to engage with the theta motor such that the theta motor is configured to rotate the theta gear.

According to another embodiment, a spindle bank for a pick-and-place machine comprises: a base including a plurality of mount locations, each of the plurality of mount locations configured to receive a mountable spindle module including at least one pick-and-place spindle and nozzle; and a bearing system attachable to a movement axis of a pick-and-place machine such that the spindle bank is movable along the movement axis.

According to another embodiment, a pick-and-place machine comprises: a feeder location configured to present electronic components for picking; a placement location configured to receive an unfinished product to place the electronic components; a first movement axis; and a spindle bank including: a base including a plurality of mount locations, each of the plurality of mount locations configured to receive a mountable spindle module including at least one pick-and-place spindle and nozzle; and a bearing system attachable to the first movement axis such that the spindle bank is movable along the first movement axis.

According to another embodiment, a method of assembly comprising: providing a pick-and-place machine having a first movement axis; providing a spindle bank for a pick-and-place machine including: a base including a plurality of mount locations; and a bearing system attachable to the first movement axis of a pick-and-place machine such that the spindle bank is movable along the axis; and mounting, on each of the plurality of mount locations, a mountable spindle module including at least one pick-and-place spindle and nozzle; and assembling, by the received mountable spindle modules, at least one unfinished product.

According to another embodiment, a pick-and-place spindle module comprises: a modular body structure including a first receiving location configured to receive a spindle; a first z-axis motor configured to move a spindle received in the first receiving location in a z-axis; a first theta motor configured to rotate a spindle received in the receiving location; an air distribution system including an air distribution port, the air distribution system configured to deliver received air from the air distribution port to a spindle

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received in the first receiving location; an electrical distribution system including an electrical distribution port, the electrical distribution system configured to deliver received electricity from the electricity distribution port to the first z-axis motor and the first theta motor; and a mechanical attachment mechanism, the mechanical attachment mechanism configured to facilitate attachment of the modular body structure to a spindle bank such that the air distribution port is connected to receive air from the spindle bank and the electrical distribution port is configured to receive electricity

According to another embodiment, a method of assembly comprises: providing a pick-and-place machine having a first movement axis; providing a spindle bank attached to the pick and place machine such that the spindle bank is movable along the first movement axis; providing a first pick-and-place spindle module including: a modular body structure including a first receiving location; a first z-axis motor; a first theta motor; an air distribution system including an air distribution port; an electrical distribution system including an electrical distribution port; and a mechanical attachment mechanism; attaching, using the mechanical attachment mechanism, the first pick-and-place spindle module to the spindle bank such that the air distribution port is connected to receive air from an element of the spindle bank and the electrical distribution port is connected to receive electricity from an element of the spindle bank; receiving, by the receiving location of the modular body structure, a first spindle; moving, by the first z-axis motor, the received first spindle in a z-axis; rotating, by the first theta motor, the received first spindle; delivering, by the air distribution system, received air from the air distribution port to the received first spindle; delivering, by the electrical distribution system, received electricity from the electrical distribution port to the received first spindle; moving the spindle bank along the first movement axis; and at least partially assembling, by the attached first pick-and-place spindle module, at least one unfinished product.

According to another embodiment, a pick-and-place machine comprises: a feeder location configured to present electronic components for picking; a placement location configured to receive an unfinished product to place the electronic components; a first movement axis; a spindle bank movable along the first movement axis; and a pick-and-place spindle module attached to the spindle bank including: a modular body structure including a first receiving location configured to receive a spindle; a first z-axis motor configured to move a spindle received in the first receiving location in a z-axis; a first theta motor configured to rotate a spindle received in the receiving location; an air distribution system including an air distribution port, the air distribution system configured to deliver received air from the air distribution port to a spindle received in the first receiving location; an electrical distribution system including an electrical distribution port, the electrical distribution system configured to deliver received electricity from the electricity distribution port to the first z-axis motor and the first theta motor; and a mechanical attachment mechanism, the mechanical attachment mechanism attaching the modular body structure to the spindle bank such that the air distribution port is connected to receive air and the electrical distribution port is configured to receive electricity.

According to another embodiment, a pick-and-place spindle module comprises: a modular body structure including a first receiving location configured to receive a spindle; a first z-axis motor configured to move a spindle received in the first receiving location in a z-axis; a first theta motor

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configured to rotate a spindle received in the receiving location; a first motion control chip each attached to the body structure, the first motion control chip configured to control the first z-axis motor and the first theta motor; and a mechanical attachment mechanism, the mechanical attachment mechanism configured to facilitate attachment of the modular body structure to a spindle bank.

According to another embodiment, a pick-and-place spindle bank comprises: a base including a plurality of mount locations; a bearing system attachable to an axis of a pick-and-place machine such that the spindle bank is movable along the axis; and a first pick-and-place spindle module mounted to a first of the plurality of mount locations, the first pick-and-place spindle module including: a modular body structure including a first receiving location configured to receive a spindle; a first z-axis motor configured to move a spindle received in the first receiving location in a z-axis; a first theta motor configured to rotate a spindle received in the first receiving location; a first motion control chip each attached to the modular body structure, the first motion control chip configured to control the first z-axis motor and the first theta motor; and a mechanical attachment mechanism attaching the modular body structure to the base.

According to another embodiment, a pick-and-place head comprises: a body structure; a plurality of z-axis motors attached to the body structure, each configured to move a spindle in a z-axis; a plurality of theta motors attached to the body structure each configured to rotate a spindle; and a plurality of motion control chips each attached to the body structure, each of the plurality of motion control chips configured to control a single one of the plurality of z-axis motors and a single one of the plurality of theta motors.

According to another embodiment, a method of assembly comprises: providing a pick-and-place head that includes: a body structure; a plurality of z-axis motors attached to the body structure, each configured to move a spindle in a z-axis; a plurality of theta motors attached to the body structure each configured to rotate a spindle; and a plurality of motion control chips each attached to the body structure, controlling, with each of the plurality of motion control chips, a single one of the plurality of z-axis motors and a single one of the plurality of theta motors; and at least partially assembling, with the pick and place head, an unfinished product.

According to another embodiment, a pick-and-place dispensing head comprises: a body structure including a first z-axis motor attachment location, a second z-axis motor attachment location, a first linear track and a second linear track; a first z-axis motor attached to the body structure at the first z-axis motor attachment location; a second z-axis motor attached to the body structure at the second z-axis motor attachment location; a first body attached to the first linear track and operably connected to the first z-axis motor such that the first body moves along the first linear track when the first z-axis motor is actuated; a second body attached to the second linear track and operably connected to the second z-axis motor such that the second body moves along the second linear track when the second z-axis motor is actuated; a first theta motor operably connected to the first body; a second theta motor operably connected to the second body; a first receiving location operably connected to the first body, the first receiving location configured to receive a pick-and-place spindle, wherein the first theta motor is configured to rotate a pick-and-place spindle received in the first receiving location; and a second receiving location operably connected to the second body, the second receiving location configured to receive a pick-and-place spindle,

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wherein the second theta motor is configured to rotate a pick-and-place spindle received in the second receiving location, wherein the first linear track and the second linear track are attached to the body structure with a set screw extending between a first nut and a second nut.

According to another embodiment, a pick-and-place dispensing head comprises: a body structure extending in an x-axis, a y-axis perpendicular to the x-axis, and a z-axis perpendicular to the x-axis and the y-axis, the body structure including a first z-axis motor attachment location, a second z-axis motor attachment location, a first linear track extending along the z-axis and a second linear track extending along the z-axis; a first z-axis motor attached to the body structure at the first z-axis motor attachment location, the first z-axis motor configured to exact movement in the z-axis; a second z-axis motor attached to the body structure at the second z-axis motor attachment location, the second z-axis motor configured to exact movement in the z-axis; a first body attached to the first linear track and operably connected to the first z-axis motor such that the first body moves along the first linear track when the first z-axis motor is actuated; a second body attached to the second linear track and operably connected to the second z-axis motor such that the second body moves along the second linear track when the second z-axis motor is actuated; a first theta motor operably connected to the first body; a second theta motor operably connected to the second body; a first receiving location operably connected to the first body, the first receiving location configured to receive a pick-and-place spindle, wherein the first theta motor is configured to rotate a pick-and-place spindle received in the first receiving location; and a second receiving location operably connected to the second body, the second receiving location configured to receive a pick-and-place spindle, wherein the second theta motor is configured to rotate a pick-and-place spindle received in the second receiving location, wherein the first receiving location and the second receiving location are spaced apart along the x-axis and located at a same location along the y-axis, wherein the first z-axis motor and the second z-axis motor are spaced apart along the x-axis and spaced apart on the y-axis.

According to another embodiment, a pick-and-place dispensing head comprises: a body structure having a z-axis motor attachment location and a linear track; a z-axis motor attached to the body structure at the axis motor attachment location, the z-axis motor configured to exact movement in a z-axis; a body attached to the linear track and operably connected to the z-axis motor such that the body moves along the linear track when the z-axis motor is actuated; a theta motor operably connected to the first body; a receiving location operably connected to the body, the receiving location configured to receive a pick-and-place spindle such that the pick-and-place spindle is configured to move relative the body in the z-axis when an upward z-axis force is applied to the pick-and-place spindle, the receiving location including a spring mechanism configured to return the spindle to a start position after actuation by the z-axis motor, and wherein the first theta motor is configured to rotate a pick-and-place spindle received in the first receiving location and remain engaged with the pick-and-place spindle during z-axis movement of the pick-and-place spindle; and an optical detector extending from the first body configured to detect upward z-axis movement of a received pick-and-place spindle relative to the body.

BRIEF DESCRIPTION OF THE DRAWINGS

Some embodiments of this invention will be described in detail, with reference to the following figures, wherein like designations denote like members, wherein:

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FIG. 1 depicts a perspective view of an assembly machine in accordance with one embodiment;

FIG. 2A depicts a perspective view of the assembly machine of FIG. 1 with covers removed in accordance with one embodiment;

FIG. 2B depicts a perspective view of a portion of the assembly machine of FIG. 2A enlarged at circle A in accordance with one embodiment;

FIG. 3 depicts a perspective view of a spindle module in accordance with one embodiment;

FIG. 4 depicts a perspective view of a body structure of the spindle module in accordance with one embodiment;

FIG. 5 depicts a front view of the body structure of FIG. 4 in accordance with one embodiment;

FIG. 6 depicts a partially exploded view of the spindle module of FIG. 3 in accordance with one embodiment;

FIG. 7A depicts a side view of the spindle module of FIG. 3 in accordance with one embodiment;

FIG. 7B depicts across sectional view of the spindle module of FIG. 7A taken at arrows A-A in accordance with one embodiment;

FIG. 8 is a perspective view of a spindle nozzle in accordance with one embodiment;

FIG. 9 is a side view of the spindle nozzle of FIG. 12 in accordance with one embodiment;

FIG. 10 depicts aside cutaway view of the spindle module of FIG. 3 in accordance with one embodiment;

FIG. 11 depicts a front view of the spindle module of FIG. 3 with the first z-axis motor actuated in accordance with one embodiment;

FIG. 12A depicts a perspective view of the spindle module of FIG. 3 with the first z-axis motor actuated in accordance with one embodiment;

FIG. 12B depicts a perspective view of a portion of the spindle module of FIG. 12A enlarged at circle B in accordance with one embodiment;

FIG. 13A depicts a perspective view of the spindle module of FIG. 3 with the first z-axis motor actuated in accordance with one embodiment;

FIG. 13B depicts a perspective view of a portion of the spindle module of FIG. 13A enlarged at circle C in accordance with one embodiment;

FIG. 14 is a perspective view of a spindle bank in accordance with one embodiment; and

FIG. 15 is a perspective view of the spindle bank of FIG. 14 with a plurality of spindle modules attached in accordance with one embodiment.

DETAILED DESCRIPTION

A detailed description of the hereinafter described embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

Referring to FIG. 1, an assembly machine 10 is shown. The assembly machine 10 is a pick-and-place machine configured to assemble printed circuit boards (PCB's) in the embodiment shown. For example, the assembly machine may be an advanced packaging assembly machine, a component assembly machine, or the like. In other embodiments, the features described herein may be applied to various other assembly machines such as odd form assembly machines (OFA), or the like. The Assembly machine 10 includes a frame 12 providing structure a body 14 having covers 16a, 16b. The frame 12 may include a plurality of legs upon which the assembly machine 10 is configured to stand. The assembly machine 10 includes a plurality of

feeder banks **18a**, **18b**. A plurality of feeders **20** are disposed (shown in FIG. 2A), attached, or otherwise mounted to each of the feeder banks **18a**, **18b**. The feeders **20** may each include a plurality of electronic components that the assembly machine **10** is configured to pick-and-place onto a PCB to assemble or at least partially assemble the PCB. The assembly machine **10** further includes a board handling opening **22**. A board handling track **24** may extend within the body **14** of the assembly machine **10** extending between the opening **22** and another opening on the opposing side of the assembly machine (not shown). The board handling track **24** may be configured to receive a PCB or another unfinished product and transport the PCB to a placement location within the body of the assembly machine **10** for assembly. The assembly machine **10** is shown further including operator interface and control displays **26a**, **26b**, one on each side. The display **26** may be configured to receive user or operator inputs and display information necessary or useful to a user or operator. While the features of the assembly machine **10** shown are one exemplary embodiment, aspects of the invention described herein are applicable to various other types of assembly machines as will be apparent to those skilled in the art.

Referring now to FIG. 2A, the assembly machine **10** is shown with the covers **16a**, **16b** removed exposing an interior **28** of the assembly machine **10**. The assembly machine **10** includes two additional feeder banks **18c**, **18d** disposed on the opposite side of the body **14** as the feeder banks **18a**, **18b**. The board handling track **24** may be located between the feeder banks **18a**, **18b** and **18c**, **18d**. The board handling track **24** may be configured to provide an unfinished product such as a PCB to a placement station **30** located along the track **24**.

The assembly machine **10** may facilitate movement of components in three movement axes: an x-axis, a y-axis and a z-axis. Hereinafter, the x-axis may be an axis extending parallel to the board handling track **24**. The y-axis may be perpendicular to the x-axis and the board handling track **24**. The z-axis may be an up and down or vertical axis. The assembly machine **10** may include a plurality of movement axes **32**, **34**, **36**, **38** for facilitating movement in the x-axis and the y-axis. In particular, the assembly machine **10** may include a first movement axis **32** and a second movement axis **34** that are configured to facilitate movement in the y-axis. The assembly machine **10** may include a third movement axis **36** and a second movement axis **38** that are configured to facilitate movement in the x-axis. The first and the second movement axis **32** may extend along a depth of the machine between a first side **40** and a second side **42**. The first side **40** is the side of the assembly machine **10** proximate the first and second feeder banks **18a**, **18b**. The second side **42** is the side of the assembly machine **10** proximate the third and fourth feeder banks **18c**, **18d**. The third and fourth movement axes **36**, **38** are shown connected to the first and second movement axes **32**, **34** and extend there between. During operation of the assembly machine **10**, the third and fourth movement axes **36**, **38** are configured to each independently move along the first and second movement axes **32**, **34** to provide for movement in the y-axis. A spindle bank **100a**, **100b** is shown movably attached to each of the third and fourth movement axes **36**, **38**, respectively. The spindle banks **100a**, **100b** may each be configured to move along the x-axis by moving along the respective third and fourth movement axes **36**, **38**. In other embodiments, the assembly machine **10** may be a single-moveable axis machine. For example, there may be a single

x-axis and a single y-axis connectable to the assembly machine, rather than two of each as shown in the embodiment in the Figures.

With the movement axes **32**, **34**, **36**, **38**, the spindle banks **100a**, **100b** within the assembly machine **10** are configured for both x-axis and y-axis freedom of operation within the interior **28**. This allows the spindle banks **100a**, **100b** to move back and forth to and from the feeder banks **18a**, **18b**, **18c**, **18d** and the placement station **30**. This is accomplished by both the movement of the spindle banks **100a**, **100b** along the respective third and fourth movement axes **36**, **38**, and the movement of the third and fourth movement axes **36**, **38** along the first and second movement axes **32**, **34**. Other forms of x-axis and y-axis movement within the assembly machine **10** are contemplated and the movement axes shown are for exemplary purposes.

Referring now to FIG. 2B, a perspective view of a portion of the assembly machine **10** enlarged at circle A (from FIG. 2A) is shown. The enlarged portion shows the spindle bank **100a** having a base **110** and a bearing system **112**. The base **110** may be a body, housing, structure or the like. The base **110** may include a plurality of mount locations **114a**, **114b**, **114c**, **114d**, **114e**, **114f**, **114g**, **114h** each configured to receive a spindle module **200a**, **200b**, **200c**, **200d**, **200e**, **200f**, **200g**, **200h**, respectively. The spindle modules described herein may be pick-and-place spindle modules particularly configured for receiving spindle and nozzle combinations that are configured to pick, place, or otherwise manipulate electronic components for printed circuit board assembly and picking and placement processes. The spindle modules described herein may also be utilized for other assembly processes where one or more rotatable and/or descendible manipulating spindles are necessary to perform at least a portion of an assembly process for assembling an unfinished product.

The bearing system **112** may be a system that provides for movement of the spindle bank **100a** along the third movement axis **36**. The bearing system **112** may include wheels to facilitate movement between the spindle bank **100a** and the movement axis **36**. In other embodiment, the bearing system **112** may include magnets to facilitate magnetic movement between the spindle bank **100a** and the third movement axis **36**. The third movement axis **36** may include a track structure on the underside (not shown) that may cooperate with a track structure bearing system of the spindle bank **100a**. For example, the spindle bank **100** may include track runner bearings configured to cooperate with a track of the third movement axis **36**. A motor or other movement creating mechanism may provide for controlled powered movement of the spindle bank **100** along the third movement axis **36**. The motor may be located on the spindle bank itself **100**, or may be located on the third movement axis **36**. Thus, the spindle bank **100** may include one or more electrical ports, connectors or the like to connect to an electrical system of the assembly machine **10** to thereby provide electrical power to the spindle bank **100**. The spindle bank **100** may utilize this electricity to power a motor or otherwise provide motion, movement, or acceleration of the spindle bank **100** relative to the third movement axis **36**.

The mount locations **114a**, **114b**, **114c**, **114d**, **114e**, **114f**, **114g**, **114h** may provide for modularity in the spindle bank **100a** such that the spindle bank **100a** may be operable with each of the spindle modules **200a**, **200b**, **200c**, **200d**, **200e**, **200f**, **200g**, **200h** attached or with a single one of the spindle modules. In other words, the spindle bank **100a** may be operable no matter how many of the spindle modules **200a**,

200b, 200c, 200d, 200e, 200f, 200g, 200h are installed into the mount locations **114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h**. If one of the spindle modules **200a, 200b, 200c, 200d, 200e, 200f, 200g, 200h** breaks or is need of repair, the spindle bank **100a** may be operable. Further, while the spindle modules **200a, 200b, 200c, 200d, 200e, 200f, 200g, 200h** shown are all the same or similar, the mount locations **114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h** may each be configured to receive different types of spindle modules with different types of spindles, nozzles and the like. The mount locations **114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h** may each have the same physical mounting properties such that the spindle modules **200a, 200b, 200c, 200d, 200e, 200f, 200g, 200h** may each include the same mounting properties, making each module interchangeably attachable to any mount location. In other embodiments, the spindle bank **100a** may include mount locations that have different physical attachment properties to provide for attachment of modules having different attachment mechanisms or properties than other modules attachable in other mount locations on the spindle bank **100a**.

Referring now to FIG. 3, a spindle module **200** is shown. The spindle module may be the same as one of the spindle modules **200a, 200b, 200c, 200d, 200e, 200f, 200g, 200h** shown in FIG. 2B. The spindle module **200** is shown including a modular body structure **210**. The modular body structure may include a first body structure **212** and a second body structure **214** mounted or attached to the first body structure **212**. The second body structure **214** includes a first receiving location **216** configured to receive a first spindle **300a**, and a second receiving location **218** configured to receive a second spindle **300b**.

The spindle module **200** further includes a first z-axis motor **220** and a second z-axis motor **222**, each mounted to the second body structure **214**. The first z-axis motor **220** may be configured to move the first spindle **300a** in the z-axis direction. Similarly, the second z-axis motor **222** may be configured to move the second spindle **300b** in the z-axis direction. The spindle module **200** further includes a first theta motor **224** and a second theta motor **226**. The first theta motor **224** may be configured to rotate the first spindle **300a** in a theta (θ) rotational axis. The second theta motor **226** may be configured to rotate the second spindle **300b** in the theta (θ) rotational axis. The first and second theta motors **224, 226** may be configured to provide theta axis rotation in either directions. Thus, the spindle module **200** may provide for movement in the z-axis and rotational movement in the theta (θ) rotational axis. The spindle module **200** may provide for independent movement for each of the first and second spindles **300a, 300b**.

The spindle module **200** may further include an air distribution system that includes one or more valves **228, 230**, first and second air distribution ports **232, 234** (shown in FIGS. 12A and 13A), along with two airflow tubes **236** (one shown), each providing vacuum generating airflow to the first and second spindles **300a, 300b**. The air distribution system may further include a pneumatic connector **256** (one shown) on each side. The first and second air distribution ports **232, 234** may each be configured to receive air from an air distribution system of the assembly machine **10** and deliver the received air to the first and second spindles **300a, 300b**. After receiving the air at the air distribution ports **232, 234**, internal airflow tubes (not shown) may provide this airflow to the pneumatic connectors **256**. The airflow tubes **236** may connect to the pneumatic connectors **256** by elongating the airflow tubes or using another tube that connects the pneumatic connectors **256** to the airflow tubes

236, respectively. In the embodiment shown, the first valve **228** is housed within a widened portion of the first body structure **214**, and may provide for air-kiss forward air pressure. The second valve **230** is also shown to be housed within a widened portion of the first body structure **214**, and may be a valve for providing vacuum pressure for picking up a component with the first and second spindles **300a, 300b**.

The spindle module **200** may have a first outer body **238a** and a second outer body **238b** mounted to the first body structure **212** with several screws. The outer bodies **238a, 238b** may be a first circuit board and a second circuit board. As shown, the spindle module **200** includes an electrical distribution system including a second circuit board assembly **251** containing a plurality of electrical distribution ports **242a, 242b** configured to receive electricity from the assembly machine **10** and/or the spindle bank **100a** or **100b** when attached and deliver the received electricity to the first and second z-axis motors **220, 222** and the first and second theta motors **224, 226**. When the spindle module **200** is attached to the assembly machine **10**, each of the electrical distribution ports **242a** and **242b** may be attached to electrical connectors of the assembly machine **10** or spindle bank **100a** or **100b**.

In one embodiment, the ports **240a, 240b** may be configured to deliver electricity from the distribution ports **242a** and **242b** to the circuit board assembly **238a** and **238b** and to electrical connectors **252, 254, 257**. It should be understood that duplicate electrical connectors to the electrical connectors **252, 254** and **257** are found on the opposite side of the outer body **238a**. Thus, electricity may travel through the port **242a** through **240a** and **238a** and through the electrical connector **257**, and through a cable (not shown) to the first z-axis motor **220**. Similarly, electricity may travel through the port **242a**, through **240a** and **238a** through the electrical connector **252** and through a cable (not shown) to the first theta motor **224**. Connector **254** may be used to connect to a spindle module optical detector **550** (described herein below, cable not shown) to the motion control chip **250** located on **238a**. This electrical arrangement may be duplicated on the other side with respect to the printed circuit board second outer body **238b**.

The spindle module **200** may include one or more mechanical attachment mechanisms to facilitate attachment of the spindle module **200** to the assembly machine **10**, for example to a spindle bank such as one of the spindle banks **100a, 100b**. In the embodiment shown, the mechanical attachment mechanisms comprise a first threaded screw **246a** and a second threaded screw **246b**. In one embodiment, the mechanical attachment mechanism may be capable of attachment with only a non-powered hand tool such as a screw driver, Allen wrench, wrench, or the like. In the embodiment shown, the first and second threaded screws **246a, 246b** may be turned by an Allen wrench at bolt heads **248a, 248b** (shown in FIG. 5). Further, the tightening of the threaded screws **246a, 246b** may be the only procedure or step required to attach the spindle module **200** to one of the spindle banks **100a, 100b**. Similarly, the loosening of the threaded screws **246a, 246b** may be the only procedure or step required to unattach or remove the spindle module **200** from one of the spindle banks **100a, 100b**.

The attachment of the spindle module **200** may be completed, executed or performed such that the air distribution ports are connectable to receive air from the assembly machine **10** and/or the spindle bank **100a** or **100b**, and the electrical distribution port is configured to receive electricity from the assembly machine **10** and/or the spindle bank **100a** or **100b**. The spindle module **200** may not be attachable

directly to any movement axis of the assembly machine 10, such as the first, second, third or fourth movement axes 32, 34, 36, 38. Instead, the spindle module 200 may be attachable to one of the spindle banks 100a, 100b which in turn may be attachable to one or more of the first, second, third or fourth movement axes 32, 34, 36, 38.

The spindle module 200 may further include a first motion control chip 250 attached to the first body structure 212 proximate the second body structure 214 and the motors 220, 222, 224, 226. An opposite side of the first body structure 212 may include a second motion control chip (not shown) in a mirrored location as the first motion control chip 250. The first motion control chip 250 may each be configured to control the first z-axis motor 220 and the first theta motor 224. The motion control chip 250 may thus be a dedicated control chip, processor, or the like, configured to control only one of the two spindles 300a, 300b contained in the spindle module 200, in particular the first spindle 300a. The second motion control chip may be a dedicated control chip, processor, or the like configured to control the second spindle 300b. Each of the first motion control chip 250 and the second motion control chip may be configured to control speed, acceleration and position of the respective first and second z-axis motors 220, 222 and the first and second theta motors 224, 226. Further, each of the first motion control chip 250 and the second motion control chip may be configured to create an independent and/or separate motion control profile for each of the first and second spindles 300a, 300b, respectively.

Referring now to FIGS. 4 and 5, a perspective view and side view, respective, of the second body structure 214 is shown prior to attachment with the first body structure 212. The second body structure 214 includes a middle structural portion 258, an upper structural portion 260 and a lower structural portion 262. The second body structure 214 may be a machined metallic component consistent with the dimensions shown. The second body structure 214 may be configured to receive for attachment the first and second z-axis motors 220, 222, and may include the support structure to allow for moveable attachment along the z-axis of the first and second theta motors 224, 226, as described in more detail herein below.

The middle structural portion 258 may include an opening 263 or bore configured to receive the second threaded screw 246b and the head 248b thereof. The middle structural portion 258 may include a square or rectangular cross section extending in the direction of the opening 263 and surrounding the opening 263. A back end of the middle structural portion 258 may include extending support flanges 264a, 264b configured for supporting the second body structure 214 when mounted to the first body structure 212.

The upper structural portion 260 extends upward from the middle structural portion 258. The upper structural portion 260 includes a depth extending from a front end 269 along the y-axis. The upper structural portion 260 includes an upper rectangular removed portion 274 configured to reduce the weight of the second body structure 214. The upper structural portion 260 includes a first z-axis motor mount face 266 and a second z-axis motor mount face 268. The first z-axis motor mount face 266 is shown flush to the front end 269 of the upper structural portion 260 while the second z-axis motor mount face 268 extends from a middle point along the depth of the upper structural portion, the middle point being closer to the front end 269 than the opposing rear end. The first z-axis motor mount face 266 and the second z-axis motor mount face 268 may be spaced apart along both the x-axis and the y-axis. Further, the first z-axis motor

mount face 266 may be facing a first direction while the second z-axis motor mount face 268 may be facing a second direction that is opposite the first direction. The first and second z-axis mount faces 266, 268 may each include a removed portion 276a, 276b configured to reduce the weight of the second body structure 214.

In one embodiment, the first and second mount faces 266, 268 may be located such that when mounted the vertical z-axes of first and second z-axis motors 220, 222 are spaced at least 18 mm apart. In other embodiments, the first and second mount faces 266, 268 may be located such that when mounted the vertical z-axes of first and second z-axis motors 220, 222 are spaced no more than 18 mm apart. In yet other embodiments, the first and second mount faces 266, 268 may be located such that when mounted the vertical z-axes of the first and second z-axis motors 220, 222 are spaced at least 16 mm apart. In one embodiment, the first and second mount faces 266, 268 may be located such that when mounted the vertical z-axes of the first and second z-axis motors 220, 222 are spaced at least 18 mm apart in total and at least 10 mm apart along the x-axis. Thus, the first and second mount faces 266, 268 may be located such that when mounted the vertical z-axes of the first and second z-axis motors 220, 222 are spaced on a diagonal relative the x-axis and the y-axis.

Extending to the top of the upper structural portion 260 is an upper stanchion 270, post, or the like configured to provide for a second attachment location. The upper stanchion 270 may include another opening 272 or bore configured to receive the first threaded screw 246a and the head 248a for attachment of the combined modular body structure 210 to the spindle bank 100a, 100b.

The lower structural portion 262 extends downward from the middle structural portion 258. The lower structural portion 262 includes a depth extending from a front end 277 along the y-axis. The lower structural portion 262 includes a lower rectangular removed portion 273 configured to reduce the weight of the second body structure 214. The lower structural portion 262 may be a U-shaped structure extending from the middle portion 258. The front end 277 of the U-shaped structure of the lower structural portion 262 includes a first linear track 278 mounted or otherwise attached to a front surface and a second linear track 280 mounted or otherwise attached to an opposing back surface such that the first linear track 278 and the second linear track 280 each extend along the z-axis.

A first body 282 is shown attached to the first linear track 278 and a second body 284 is shown attached to the second linear track 280. As shown in FIGS. 7-8 and described herein below, the first body 282 is operably connected to the first z-axis motor 220 such that the first body 282 moves along the first linear track 278 when the first z-axis motor 220 is actuated. Similarly, the second body 284 is operably connected to the second z-axis motor 222 such that the second body 284 moves along the second linear track 280 when the second z-axis motor 222 is actuated. The first and second bodies 282, 284 may each be linear bearing systems configured to integrate with the first and second linear tracks 278, 280, respectively. In one embodiment, the first and second bodies 282, 284 may be configured to slidably move along the first and second linear tracks 278, 280, respectively. In other embodiments, the first and second bodies 282, 284 may house rollers or wheels configured to facilitate movement along the first and second tracks 278, 280. To attach the first and second bodies 282, 284 to the first and second tracks 278, 280, respectively, the first and second bodies 282, 284 may be slid into the track from the bottom.

Once the first and second bodies **282**, **284** are operably connected to the first and second z-axis motors **220**, **222**, respectively, the downward z-axis motion of the first and second bodies **282**, **284** may be restricted by the movement of the first and second z-axis motors **220**, **222** in order to securably attach the first and second bodies **282**, **284** onto the first and second tracks **278**, **280**.

Referring now to FIG. 6, a partially exploded view of the second body structure **214** is shown having the first z-axis motor **220** and the second z-axis motor **222** already attached, the first theta motor **224** and the second theta motor **226** disassembled from the second body structure **214**, and the first and second spindles **300a**, **300b** disassembled from the first and second receiving locations **216**, **218**, respectively. A third body structure **286** is shown attached to the first body **282** and a fourth body structure **288** is shown attached to the second body **284**. The third and fourth body structures **286**, **288** are shown attached to the first and second bodies **282**, **284** through screws or bolts **290a**, **290b** which may be threadably received by openings **291a**, **291b** (shown in FIG. 4) in the first and second bodies **282**, **284**. The third and fourth body structures **286**, **288** may be configured for attaching the first and second theta motors **224**, **226** to the movable first and second bodies **282**, **284**. In this manner, the first and second theta motors **224**, **226** may be operably connected to the first and second bodies **282**, **284**, respectively. The third and fourth body structures **286**, **288** may include the first and second receiving locations **216**, **218**, respectively for receiving the first and second spindles **300a**, **300b**. Further, the third and fourth body structures **286**, **288** may include a location at the top that interfaces with and/or otherwise attaches to an extending portion of the z-axis motor **220**, **222**.

Each of the third and fourth body structures **286**, **288** may include a theta motor attachment location **292**, **294** configured to receive the first and second theta motors **224**, **226**, respectively. The theta motor attachment locations **292**, **294** may each be semi-circular in shape. The theta motor attachment locations **292**, **294** may be offset from the receiving locations **292**, **294**, respectively, such that motor drive gears **295**, **296** of the first and second theta motors **224**, **226** may be meshed with theta gears **310** of the spindle **300a**, **300b**. In one embodiment, the first receiving location **216** and the second receiving **218** location spaced apart by a spacing **S** equal to or less than 10 mm. In other embodiments, the spacing **S** may be equal to or less than 8 mm. In still other embodiments, the spacing may be equal to or less than 12 mm.

Referring now to FIGS. 7A and 7B, a mechanism and method for connecting the first and second linear tracks **278**, **280** to the second body structure **214** is shown. In particular, FIG. 7A shows a side view of the spindle module **200**. FIG. 7B shows a cross sectional view of the second body structure **214** of the spindle module **200** at a location where the first and second linear tracks **278**, **280** are connected, taken at arrows A-A. As shown in FIG. 7B, the first linear track **278** and the second linear track **280** are attached to the lower structural portion **262** of the second body structure **214** of the modular body structure **210** of the spindle module **200** with a set screw **297** extending between a first nut **298a** and a second nut **298b**. The set screw **297** may include exterior threads as shown. Each of the first and second nuts **298a**, **298b** may include an internally threaded nut body **299a**, **299b** configured to receive the exterior threads of the set screw **297**.

The first and second linear tracks **278**, **280** may include bores **291a**, **291b**, configured to receive a heads **293a**, **293b**,

respectively, of the first and second nuts **298a**, **298b**. In particular, the first linear track **278** may include the first bore **291a** configured to receive the first head **293a** of the first nut **298a** when tightened such that the first nut **298a** does not interfere with movement of the first body **282** on the first linear track **278**. Similarly, the second linear track **280** may include a second bore **291b** configured to receive the second head **293b** of the second nut **298b** when tightened such that the second nut **293b** does not interfere with movement of the second body **284** on the second linear track **280**.

To connect the first and second linear tracks **278**, **280** to the second body structure **214**, the process includes inserting the set screw **297** into an opening in each of the first and second linear tracks **278**, **280** while aligned with an opening of the second body structure **214**, then inserting the nuts **298a**, **298b** such that the internally threaded nut body **299a**, **299b** engages with the external threads of the set screw **297**. Next, the process includes tightening the first and second nuts **298a**, **298b** until tight. In one embodiment, only a single set screw and nut combination may be required to fully attach the first and second linear tracks **278**, **280**. In another, a second set screw may extend between a third nut and a fourth nut at a spaced apart location from the first set screw **297**, the first nut **298a**, and the second nut **298b**.

Referring now to FIGS. 8 and 9, a spindle **300** is shown. In particular, FIG. 8 shows a perspective view of the spindle **300** and FIG. 9 shows a side view of the spindle. The spindle **300** may include the same features as the spindles **300a**, **300b**. The spindle **300** includes a theta gear **310**, a shaft **312** and a nozzle tip **314**. The spindle **300** may extend between a first lower end **328** and a second upper end **330**.

The spindle **300** may be considered a spindle-nozzle combination. The nozzle tip **314** is configured to contact an electronic component for manipulation of the electronic component. Additionally, the spindle **300** may include the rotatable shaft **312** and the theta gear **310** to facilitate rotation. The spindle **300** may be configured for interchangeability on, or removably attachable to, a dispensing or pick-and-place head (such as the spindle bank **100** and the spindle module **200** combination). The spindle **300** may be found in a nozzle bank of the assembly machine **10** when it is not attached to the spindle module **200** and/or spindle bank **100**.

The spindle **300** may be configured to provide vacuum suction to the electronic component through the nozzle tip **314** to allow for the picking up, or other manipulation, of electronic components by the nozzle tip **314**. To provide airflow or a vacuum force to the nozzle tip **314**, the shaft **312** may include an outer body **316** having a hollow interior **318**. The spindle **300** may be configured to provide an airkiss outward airflow through the nozzle tip **314** to the electronic component to facilitate placement of electronic components. In other embodiments, other types of nozzles may be contemplated for the spindle **300**, such as nozzles configured to provide a material to an unfinished product.

The theta gear **310** may be disposed onto the shaft **312**. The theta gear **310** may include a plurality of teeth **320** evenly disposed about the circumference of the theta gear **310**. The teeth **320** of the theta gear **310** may be configured to engage with a theta motor such as one of the theta motors **224**, **226**. For example, the teeth **320** may be configured to engage with a motor drive gear, such as one of the motor drive gears **295**, **296**, of the theta motors **224**, **226**.

The shaft **312** may be cylindrical in shape. The theta gear **310** may be secured to, attached to, or otherwise integrated with, the shaft **312** such that rotation of the theta gear **310** by a motor drive gear also rotates the shaft **312**. In some

embodiments, the theta gear **310** may be a separately manufactured component from the shaft **312**. The theta gear **310** may include a circular inner opening configured to receive the shaft **312**.

The outer body **316** of the rotatable shaft **312** includes a first opening **322** configured to receive airflow into the hollow interior **318**. For example, the airflow tube **236** of the spindle module **200** may be configured to deliver airflow through the first opening **322** into the hollow interior. The outer body **316** of the rotatable shaft **312** includes a second opening **324** configured to receive airflow into the hollow interior **318**. The airflow tube **236** of the spindle module **200** may be configured to deliver airflow through the second opening **324** into the hollow interior. The second opening **324** may be disposed on an opposite side of the rotatable shaft **312** than the first opening **322**. While the embodiment shown in FIGS. **8** and **9** includes two openings **322**, **324**, more or less openings are contemplated. As shown, the each of the first and second openings **322**, **324** may be disposed about the outer body **316** of the rotatable shaft **312** at a point along a length of the shaft.

The theta gear **310** may further include an upper surface **326** facing the second upper end **330**, and a lower surface **332** facing the first lower end **328**. The theta gear **310** may include an outer circumference with the teeth **320** disposed along the outer circumference. The theta gear **310** may further include a circumferential ridge **334** extending from the upper surface **326** toward the first lower end **328**. The circumferential ridge **334** may be a ring, protrusion, or the like, and may be located between the outer circumference of the theta gear **310** and the shaft **312**.

The theta gear **310** may further include a lower base **336** and an upper base **338**. The lower base **336** may extend from the lower surface **332** toward the first lower end **328** of the spindle **300**. The lower base **336** may be located proximate the opening of the theta gear **310** and may extend along a length of the opening of the theta gear **310** and along a length of the shaft **312**. The lower base **336** and the upper base **338** may be configured to provide support for the attachment of the theta gear **310** to the shaft **312**.

In one embodiment, the shaft **312** may be made of a magnetic material to facilitate magnetic attachment of the spindle **300** to a receiving location, such as one of the receiving locations **216**, **218**, of a dispensing head or pick-and-place head such as the spindle module **200** and/or the spindle bank **100**. The magnetic material may provide for removable attachment of the spindle **300** to the dispensing head or pick-and-place head, as described hereinbelow.

The spindle **300** is shown as a spindle-nozzle combination that includes a toothed arrangement for being driven by a tooth drive gear. However, the spindle **300** may also be a spindle-nozzle combination where the theta gear is a magnetic gear rather than a toothed gear. A magnetic theta gear may be driven by a magnetic theta motor. Whatever drive mechanism utilized the spindle **300** may include a nozzle and an integrated means to provide for rotation of the nozzle.

Referring now to FIG. **10**, aside cutaway view of the spindle module **200** of FIG. **3** is shown. In particular, FIG. **10** shows the attachment of the first z-axis motor **220** to the third body structure **286**. It should be understood that the features that are described hereinbelow as shown with respect to the first z-axis motor **220** and the third body structure **286** may be applicable to the second z-axis motor **222** connecting to the fourth body structure **288**.

Each of the first and second z-axis motors **220**, **222** includes a movable shaft **516a**, **516b**, respectively, each configured to move relative to the body of the motor. Each

of the first and second z-axis motors **220**, **222** includes a spring **518a**, **518b** proximate a cap **520a**, **520b**. The springs **518a**, **518b** may be configured to return the movable shaft **516a**, **516b** to the start position after actuation by the z-axis motor **220**, **222**. The top end of each of the shafts **516a**, **516b** is connected to the respective caps **520a**, **520b** by a threaded feature of the cap being inserted into a threaded bore of the shafts **516a**, **516b**. A threaded set screw **514** may be located at the bottom of each of the shafts **516a**, **516b** connecting the shaft to the third and fourth body structures **286**, **288**, respectively. Thus, when the z-axis motors **220**, **222** are actuated and the shafts **516a**, **516b** displace downward, so do the respective attached body structures, which includes the respective nozzles **300a**, **300b**, and the respective theta motors **224**, **226**.

Furthermore, the first receiving location **216** is shown after having received the first spindle **300a** into a bore of the first receiving location **216**. The first receiving location **216** and the shaft **312** of the first spindle **300a** may include a relatively tight tolerance to allow for z-axis sliding and rotation of the shaft **312** without other movement. The shaft **312** of the first spindle **300a** may be magnetic and may be attracted to a magnet **510** located or disposed within the third body structure **286**. This may create a holding force to retain the first spindle **300a** within the first receiving location **216**. However, this holding force may be overcome by a greater force if it is desired for the first spindle **300a** to be removed from the first receiving location **216**. In this manner, the first spindle **300a** may be removably attachable to the first receiving location **216**. As shown a spindle spring **512** may be housed within the third body structure **286**. This spindle spring **512** may provide a small amount of spring movement at the moment of pickup and/or placement of a component by the spindle **300a**, when the spindle **300a** is resisted by the upward force from the unmovable feeder bank (during pickup) and unfinished product or PCB (during placement). In other embodiments not shown, the spindle spring **512** may be replaced by a magnet that provides a resistive magnetic force on a corresponding magnet of the spindle **300a**.

FIG. **11** depicts a front view of the spindle module **200** with the first z-axis motor **220** actuated. As shown, the second z-axis motor **222** remains in the upward and non-actuated position. When actuated, the shaft **516a** and spring **518a** are compressed. When actuated, the shaft **518a** then protrudes from the bottom of the body of the z-axis motor **220**. An attachment location **522a** between the shaft **518a** and the third body structure **286** is thereby moved down, moving down the first body **282**, the first theta motor **224**, the first receiving location **216** and the first spindle **300a**. Meanwhile, an attachment location **522b** between the shaft **518b** and the fourth body structure **288** remains stationary, along with the second body **284**, the second theta motor **226**, the second receiving location **218** and the second spindle **300b**.

FIG. **12A** depicts a perspective view of the spindle module **200** with the first z-axis motor **220** actuated and having a circle B drawn around a portion of the spindle **300a**. FIG. **12B** depicts a perspective view of a portion of the spindle module **200** enlarged at the circle B. The enlarged view from FIG. **12B** shows a spindle module optical detector **550** extending from the third body structure **282** attached to the first body **282**. The optical detector **550** may be configured to detect upward movement of the received first spindle **300a** relative to the first body **282** and the third body structure **282**. It should be understood that the spindle module **200** may include a second optical detector posi-

tioned in the same manner detecting movement of the second received spindle **300b**.

As shown in FIG. 12B, the spindle **300a** is in a resting downward position before the spindle **300a** contacts an electronic component for picking up, or before the spindle **300a** contacts the PCB or other unfinished product during placement. During this resting position, the teeth **320** of the spindle **300a** mesh with the teeth of the first theta motor drive gear **295**. Further, the circumferential ridge **334** of the first spindle **300a** does not extend into an opening **552** located between a first end **554** and a second end **556** of the optical sensor **550**. The first end **554** of the optical sensor **550** may include an optical light beam generator **558** and the second end **556** of the optical sensor **550** may include an optical light detector. When the circumferential ridge **334** is positioned in the opening **552**, the circumferential ridge **334** may break the beam. This may be configured to immediately detect when touchdown has occurred during pickup and/or placement.

FIG. 13A depicts a perspective view of the spindle module **200** with the first z-axis motor **220** actuated and having a circle C drawn around a portion of the spindle **300a**. FIG. 13B depicts a perspective view of a portion of the spindle module **200** enlarged at circle C. As shown in FIG. 13B, the spindle **300a** has now been moved upward relative to the first body **282** and the third body structure **282**. Thus, the circumferential ridge **334** is positioned in the opening **552**, thereby breaking the beam of the optical sensor **550**. It should further be noted that the first theta motor drive gear **295** includes a height that is large enough to maintain contact with the teeth **320** of the nozzle **300a** during motion of the nozzle **300a** relative to the first theta motor drive gear **295**. In one embodiment, the first theta motor drive gear **295** may include a height that is larger than the maximum movement allowable between the spindle **300a** and the first body **282** and the third body structure **282**.

Referring first to FIG. 14, the spindle bank **100** having a single one of the spindle modules **200** attached. The spindle bank **100** includes the base **110** and the mounting locations **114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h**. In the embodiment shown, the base **110** includes eight of the mounting locations **114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h**. In other embodiments, more or less mounting locations are contemplated. For example, a spindle bank may have as little as a single mounting location, or as many mounting locations as would, when attached to the spindle bank **100**, span across half the width of the assembly machine, minus half the width of the intended unfinished product the assembly machine is intended to at least partially assemble. Such an arrangement would enable even the left and rightmost spindles in the spindle module to reach each point along the x-axis of the unfinished product.

Each of the plurality of mount locations **114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h** are configured to receive a mountable spindle module, such as the mountable spindle module **200** as shown. The spindle bank **100**, when combined with one or more spindle modules **200** may be a dispensing head or pick-and-place head for the assembly machine **10**. Unlike typical dispensing heads and pick-and-place heads, the spindle bank **100** may provide a modular design for simple mechanical attachment and removal of individual modular spindle modules, such as the spindle module **200**. The modular nature of the spindle attachment may provide for simpler maintenance when a spindle assembly needs repair. Further, while the spindle module **200** was described hereinabove as an example, various other spindle modules may fit into the spindle bank **100**, such as the

spindle module **500**, shown in FIG. 15. The modularity of the spindle bank **100** and spindle module combination may provide flexibility to the system. The dispensing head defined by the spindle bank **100** and the spindle modules **200, 500** can be easily reconfigured with various spindle modules in whatever configuration needed by an assembly process.

In the embodiment shown, the center of each of the mount locations **114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h** may be spaced less than 25 mm apart. In other embodiments, the center of each of the mount locations **114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h** may be spaced less than 20 mm apart. Any spacing is contemplated for the mount locations **114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h**, but it may be difficult but desirable to reduce the spacing by making each of the spindle modules **200** as thin as possible in order to reduce the size and weight of the spindle bank **100**. The above described structure of the spindle module includes various features that provide for thin spindle modules **200** such as the spacing of the z-axis motors **220, 222**, the features of the modular body structure **210**, and the like.

The spindle bank **100** includes a bearing system **112** comprising a first bearing **116** and a second bearing **118** for attaching the spindle bank **100** to the movement axis of an assembly machine, such as the third movement axis **36** or the fourth movement axis **38**. The bearing system **112** may cooperate with a track found in the movement axis **36, 38** of the assembly machine **10**. In other embodiments, the bearing system **112** of the spindle bank **100** may include wheels or balls to facilitate movement (not shown). In other embodiments, the bearing system **112** may include other shaped channels for integrating with a track system. In still others, the spindle bank **100** may include a powered bearing system that uses wheels or magnetism to move the spindle bank **100** along the attached movement axis. In others, the axis includes the movement system and the spindle bank **100** is unpowered for the purposes of movement but instead attaches to the axis and is moved by the movement system powered by the axis. In some embodiments, a permanent magnet and coil system may be utilized in which the spindle bank **100** acts as either the permanent magnet(s) or the moveable coil(s), and the axis acts as the other of the permanent magnet(s) or the movable coil(s). The spindle bank **100** may include any system for movably attaching the spindle bank **100** to one or more axis for movement.

The spindle bank **100** further includes an air distribution system including a first inlet **122** and a second inlet **124**. The first inlet **122** and the second inlet **124** may each be connected to a tube or other air delivery system from the assembly machine. A channel may extend from the first air inlet **122** with various air outlets **126a, 126b, 126c, 126d, 126e, 126f, 126g** configured to each deliver air to an air distribution port, such as the first air distribution port **232** of the spindle module **200**. Similarly, a channel may extend from the second air inlet **124** with various air outlets **128a, 128b, 128c, 128d, 128e, 128f, 128g** configured to each deliver air to an air distribution port, such as the second air distribution port **234** of the spindle module **200**. It should be understood two air outlets of the spindle bank **100** are hidden by the attached spindle module **200** in the embodiment shown in FIG. 14. In this manner, the plurality of mount locations **114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h** may each be configured to deliver air to each of the mountable spindle modules when the modules are mounted.

The spindle bank **100** may further include a power delivery system to delivery electrical power and/or signals to each of the plurality of mount locations **114a, 114b, 114c,**

114d, 114e, 114f, 114g, 114h. The power delivery system is shown including a set of electrical connectors 132. The set of electrical connectors 132 may be configured to connect to the electrical distribution ports 242a, 242b of each of the spindle modules 200. The spindle bank 100 may include one or more electrical input connectors (not shown) to provide electrical power and/or other signals to the spindle bank 100 that are wired to the electrical connectors 130, 132 disposed at the plurality of mount locations 114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h.

Each of the plurality of mount locations 114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h may include a first threaded attachment location 134 configured to receive the first threaded screw 246a of the spindle module 200. Each of the plurality of mount locations 114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h may include a second threaded attachment location 136 configured to receive the second threaded screw 246b of the spindle module 200. The first threaded attachment locations 134 and the second threaded attachment locations 136 may each be threaded bores. Thus, as described above, each spindle module 200 may be mounted and removed from the spindle bank 200 by the application or removal of two threaded screws. A hand tool, such as a screwdriver, Allen wrench, wrench, or the like may be the only tool necessary for attachment of the spindle modules 200 to the spindle bank 100.

FIG. 15 shows a plurality of spindle modules 200a, 200b, 200c, 200d, 200e, 200f, 200g attached, along with the spindle module 500 that is different from the spindle modules 200a, 200b, 200c, 200d, 200e, 200f, 200g. Thus, the plurality of mount locations 114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h includes a first mount locations 114a configured to receive a first mountable spindle module 500. The plurality of mount locations 114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h may include second mount locations 114b, 114c, 114d, 114e, 114f, 114g, 114h each configured to receive a second mountable spindle module 200. In some embodiments, the first mount location 114a and the second mount locations 114b, 114c, 114d, 114e, 114f, 114g, 114h may be structurally the same. In other embodiments, the spindle bank 100 may include structural differences between mount locations. Thus, the first mountable spindle module 500 is different than the second mountable spindle modules 200a, 200b, 200c, 200d, 200e, 200f, 200g. For example, the first mountable spindle module 500 includes a single spindle and nozzle, while each of the second mountable spindle modules 200a, 200b, 200c, 200d, 200e, 200f, 200g include two spindle and nozzles. In accommodating different spindle modules, the first mount location 114a may include at least one different physical property than the second mount locations 114b, 114c, 114d, 114e, 114f, 114g, 114h. Spindle banks accommodating various different spindle modules with differences in features or physical properties at the mount locations are contemplated.

While not shown, it is also contemplated that the spindle bank 100 includes one or more motion control chips for each of the plurality of mount locations 114a, 114b, 114c, 114d, 114e, 114f, 114g, 114h. The embodiment shown includes the motion control chips 250 attached to each of the attachable spindle modules 200. However, in other embodiments, these motion control chips may be found on the spindle bank 100. Whatever the embodiment, the dispensing head or pick-and-place head defined by the combination of the spindle bank 100 and the attached spindle modules 200, 500 may include a number of control chips 250 equal to the number of spindles. In other embodiments, each spindle module 200

includes a single one of the control chips 250 dedicated to the two spindles located on the module.

Various methods are contemplated for assembling unfinished products, or assembling assembly machines, utilizing the assembly machines, dispensing heads, spindles, spindle mounting modules and spindle banks described herein-above.

For example, a method of assembly may include providing a pick-and-place machine, such as the assembly machine 10, having a pick-and-place head, such as the combination of the spindle banks 100 and one or more of the spindle modules 200. The method may include providing a spindle, such as the spindle 300, for the pick-and-place machine. The method may include attaching the spindle to the pick-and-place head of the pick-and-place machine. The method may include engaging, by a theta gear of the spindle, with a motor, such as the first theta motor 224, of the pick-and-place head. The method may include contacting, by the spindle, an electronic component, or a portion thereof. The method may include manipulating, by the spindle, the electrical component. The method may include removing the spindle from the pick-and-place head of the pick-and-place machine to a spindle bank of the pick-and-place machine. The method may include receiving, by at least one opening in the shaft of the spindle, air flow into a hollow interior of the spindle from an air delivery system of the pick-and-place head and utilizing the airflow during the manipulating. The method may include picking up, with the nozzle, the electrical component using the airflow, and placing, with the nozzle, the electronic component using the airflow. The method may include rotating, with the motor of the pick-and-place head, the theta gear of the spindle and rotating, by the rotating of the theta gear, the shaft and the nozzle tip of the spindle. The method may include breaking, by a circumferential ridge of the spindle, a beam of an optical sensor, such as the optical sensor 550, disposed on the pick-and-place head. The method may include sensing, by the optical sensor, movement by the nozzle relative to at least a portion of the pick-and-place head. The method may include rotating, by the motor, the theta gear by a magnetic force. The method may include receiving, by a magnet of a receiving location of the pick and place head, the shaft such that the magnetic material interacts with the magnet of the receiving location.

Another method of assembly may include providing a pick-and-place machine, such as the assembly machine 10 having a first movement axis, such as the third movement axis 36 or the fourth movement axis 38. The method may include providing a spindle bank, such as the spindle bank 100, for a pick-and-place machine. The method may include mounting, on each of a plurality of mount locations of the spindle bank, a mountable spindle module, such as the spindle module 200, 500, including at least one pick-and-place spindle and nozzle, such as the spindle and nozzle combination 300. The method may include assembling, by the received mountable spindle modules, at least one unfinished product. The method may include distributing air, by an air distribution system of the assembly machine, to the spindle bank, and distributing the air, by a second air distribution system of the spindle bank, to each of the mountable spindle modules after the mounting. The method may include distributing electrical power, by an electrical power distribution system of the assembly machine, to the spindle bank, and distributing the electrical power, by a second electrical power distribution system of the spindle bank, such as the electrical connectors 130, 132, to each of the mountable spindle modules after the mounting. The

method may include receiving, by at least one threaded attachment location of the spindle bank such as the threaded attachment locations **134**, **136**, at least one threaded attachment component of the at least one of the mountable spindle modules, such as the screws **246a**, **246b**. The method may include using, by an installer, only a hand tool and attaching the at least one of the mountable spindle modules to a selected one of the plurality of mount locations. The method may include attaching a bearing system of the spindle bank, such as the bearing system **112**, to the first movement axis. The method may include moving the spindle bank along the first movement axis by the pick-and-place machine. The method may include attaching the first movement axis to a second movement axis of the pick-and-place machine, such as the first movement axis **32** and/or the second movement axis **34**, and moving the spindle bank along the second movement axis by the pick-and-place machine. The method may include mounting a first mountable spindle module to a first mount location of the spindle bank and mounting the second mountable spindle module to a second mount location, wherein the second mountable spindle module is different than the first and wherein the second mount location includes different physical properties than the first mount location.

Another of assembly may include providing a pick-and-place machine, such as the assembly machine **10**, having a first movement axis, such as the third movement axis **36** or the fourth movement axis **38**. The method may include providing a spindle bank, such as the spindle bank **100** attached to the pick and place machine such that the spindle bank is movable along the first movement axis. The method may include providing a first pick-and-place spindle module, such as the spindle module **200**. The method may include attaching, using a mechanical attachment mechanism such as the screws **246a**, **246b**, the first pick-and-place spindle module to the spindle bank such that an air distribution port, such as one of the air distribution ports **232**, **234**, is connected to receive air from an element, such as air outlets **126a**, **126b**, **126c**, **126d**, **126e**, **126f**, **126g** of the spindle bank and the electrical distribution port, such as the electrical distribution ports **240a**, **240b**, **242a**, **242b** is connected to receive electricity from an element, such as the electrical connectors **130**, **132** of the spindle bank. The method may include receiving, by a receiving location of the modular body structure, a first spindle, such as the spindle **300**. The method may include moving, by a first z-axis motor such as the z-axis motor **220**, the received first spindle in a z-axis. The method may include rotating, by a first theta motor such as the first theta motor **224**, the received first spindle. The method may include delivering, by the air distribution system, received air from the air distribution port to the received first spindle. The method may include delivering, by the electrical distribution system, received electricity from the electrical distribution port to the received first spindle. The method may include moving the spindle bank along the first movement axis and at least partially assembling, by the attached first pick-and-place spindle module, at least one unfinished product. The method may include attaching the first pick-and-place spindle module to the spindle bank with a hand tool. The method may include receiving, by a second receiving location of the modular body structure, a second spindle such as the spindle **300**. The method may include moving, by a second z-axis motor such as the second z-axis motor **222**, the received second spindle in the z-axis. The method may include rotating, by a second theta motor such as the second theta motor **226**, the received second spindle. The method may

include delivering, by the air distribution system, received air from the air distribution port to the received second spindle and delivering, by the electrical distribution system, received electricity from the electrical distribution port to the received second spindle. The method may include moving, by the first z-axis motor, a first body, such as the first body **282**, along a first linear track, such as the first linear track **278**. The method may include moving, by the second z-axis motor, the second body, such as the second body **284**, along a second linear track, such as the second linear track **280**. The method may include attaching the first linear track and the second linear track to the modular body structure with a set screw, such as the set screw **297** extending between a first nut and a second nut, such as the first and second nuts **298a**, **298b**.

The method may further include controlling, with a first motion control chip of the spindle module, such as the motion control chip **250**, the first z-axis motor and the first theta motor. The method may include controlling, with a second motion control chip, the second z-axis motor and the second theta motor.

The method of assembly may also include providing a second pick-and-place spindle module, such as the spindle module **500** or **200**. The method may include attaching, using the mechanical attachment mechanism, the second pick-and-place spindle module to the spindle bank such that the air distribution port of the second pick-and-place spindle module is connected to receive air from an element of the spindle bank and the electrical distribution port of the second pick-and-place spindle module is connected to receive electricity from an element of the spindle bank. The method may include receiving, by a receiving location of a modular body structure of the second pick-and-place spindle module, a spindle. The method may include moving, by the first z-axis motor of the second pick-and-place spindle module, the received spindle of the second pick-and-place spindle module in a z-axis. The method may include rotating, by the first theta motor of the second pick-and-place spindle module, the received spindle of the second pick-and-place spindle module. The method may include delivering, by the air distribution system of the second pick-and-place spindle module, received air from the air distribution port of the second pick-and-place spindle module to the received spindle of the second pick-and-place spindle module. The method may include delivering, by the electrical distribution system of the second pick-and-place spindle module, received electricity from the electrical distribution port of the second pick-and-place spindle module to the received spindle of the second pick-and-place spindle module. The method may include at least partially assembling, by the attached second pick-and-place spindle module, the at least one unfinished product. The method may still further include controlling, with a first motion control chip, the first z-axis motor of the first pick-and-place spindle module and the first theta motor of the first pick-and-place spindle module, and controlling, with a second motion control chip, the first z-axis motor of the second pick-and-place spindle module and the first theta motor of the second pick-and-place spindle module.

Methods of assembly may further include providing a pick-and-place head that includes a body structure such as the modular body structure **210** and/or the base **110** of the spindle bank **100**, or any other body for a pick-and-place or dispensing head. The method may include providing a plurality of z-axis motors attached to the body structure, each configured to move a spindle in a z-axis and a plurality of theta motors attached to the body structure each config-

ured to rotate a spindle. The method may include providing a plurality of motion control chips each attached to the body structure. The method may include controlling, with each of the plurality of motion control chips, a single one of the plurality of z-axis motors and a single one of the plurality of theta motors, and at least partially assembling, with the pick and place head, an unfinished product. The method may include controlling, with each of the plurality of motion control chips, speed of a single one of the plurality of z-axis motors and a single one of the plurality of theta motors. The method may include controlling, with each of the plurality of motion control chips, acceleration of a single one of the plurality of z-axis motors and a single one of the plurality of theta motors. The method may include controlling, with each of the plurality of motion control chips, position of a single one of the plurality of z-axis motors and a single one of the plurality of theta motors. The method may still further include creating, with each of the plurality of motion control chips, a separate independent motion control profile for each of the plurality of spindles.

Elements of the embodiments have been introduced with either the articles “a” or “an.” The articles are intended to mean that there are one or more of the elements. The terms “including” and “having” and their derivatives are intended to be inclusive such that there may be additional elements other than the elements listed. The conjunction “or” when used with a list of at least two terms is intended to mean any term or combination of terms. The terms “first” and “second” are used to distinguish elements and are not used to denote a particular order.

While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

What is claimed:

1. A method of assembly comprising:
 providing a pick-and-place machine having a first movement axis;
 providing a spindle bank attached to the pick-and-place machine such that the spindle bank is movable along the first movement axis, the spindle bank including:
 a spindle bank air distribution system including at least one air inlet and a plurality of air outlets;
 providing a first pick-and-place spindle module including:
 a modular body structure including a first receiving location;
 a first z-axis motor;
 a first theta motor;
 a spindle module air distribution system including an air distribution port;
 an electrical distribution system including an electrical distribution port; and
 a mechanical attachment mechanism;
 attaching, using the mechanical attachment mechanism, the first pick-and-place spindle module to the spindle bank such that the air distribution port of the spindle module air distribution system is connected to receive

air from one of the plurality of air outlets of the spindle bank air distribution system of the spindle bank and the electrical distribution port is connected to receive electricity from the electrical distribution system of the first pick-and-place spindle module of the spindle bank;
 receiving, by the receiving location of the modular body structure, a first spindle;
 moving, by the first z-axis motor, the received first spindle in a z-axis;
 rotating, by the first theta motor, the received first spindle;
 delivering, by the spindle module air distribution system, received air from the air distribution port to the received first spindle;
 delivering, by the electrical distribution system, received electricity from the electrical distribution port to the received first spindle;
 moving the spindle bank along the first movement axis;
 and
 at least partially assembling, by the attached first pick-and-place spindle module, at least one product.

2. The method of assembly of claim **1**, wherein the mechanical attachment mechanism is a plurality of threaded bolts, the method further comprising:

attaching the first pick-and-place spindle module to the spindle bank with a hand tool.

3. The method of assembly of claim **1**, wherein the modular body structure further includes a second receiving location, the pick-and-place spindle module further comprising:

a second z-axis motor; and

a second theta motor,

the method further comprising:

receiving, by the second receiving location of the modular body structure, a second spindle;

moving, by the second z-axis motor, the received second spindle in the z-axis;

rotating, by the second theta motor, the received second spindle;

delivering, by the spindle module air distribution system, received air from the air distribution port to the received second spindle; and

delivering, by the electrical distribution system, received electricity from the electrical distribution port to the received second spindle.

4. The method of assembly of claim **3**, wherein the modular body structure further includes a first linear track and a second linear track, the first pick-and-place spindle module further comprising:

a first body attached to the first linear track and operably connected to the first z-axis motor; and

a second body attached to the second linear track and operably connected to the second z-axis motor, wherein the first theta motor is operably connected to the first body and the second theta motor is operably connected to the second body, the method further comprising:

moving, by the first z-axis motor, the first body along the first linear track; and

moving, by the second z-axis motor, the second body along the second linear track.

5. The pick-and-place spindle module of claim **4**, further comprising:

attaching the first linear track and the second linear track to the modular body structure with a set screw extending between a first nut and a second nut.

6. The method of assembly of claim **3**, the first pick-and-place spindle module further comprising:

a first motion control chip; and

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a second motion control chip,
 the method of assembly further comprising: controlling,
 using the first motion control chip, speed and accelera-
 tion of the first z-axis motor and the first theta motor;
 and
 controlling, using the second motion control chip, speed
 and acceleration of the second z-axis motor and the
 second theta motor.

7. The method of assembly of claim 1, further comprising:
 providing a second pick-and-place spindle module includ-
 ing:

- a second pick-and-place spindle modular body struc-
 ture including a receiving location;
- a second pick-and-place spindle first z-axis motor;
- a second pick-and-place spindle first theta motor;
- a second pick-and-place spindle module air distribu-
 tion system including a second pick-and-place spindle air
 distribution port;
- a second pick-and-place spindle electrical distribution
 system including a second pick-and-place spindle
 electrical distribution port; and
- a second pick-and-place spindle mechanical attachment
 mechanism;

attaching, using the second pick-and-place spindle
 mechanical attachment mechanism, the second pick-
 and-place spindle module to the spindle bank such that
 the second pick-and-place spindle air distribution port
 is connected to receive air from the spindle bank and
 the second pick-and-place spindle electrical distribu-
 tion port is connected to receive electricity from the
 spindle bank;

receiving, by the second pick-and-place spindle receiving
 location of the second pick-and-place spindle modular
 body structure, a spindle;

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moving, by the second pick-and-place spindle first z-axis
 motor of the second pick-and-place spindle module, the
 received spindle of the second pick-and-place spindle
 module in a z-axis;

rotating, by the second pick-and-place spindle first theta
 motor of the second pick-and-place spindle module, the
 received spindle of the second pick-and-place spindle
 module;

delivering, by the second pick-and-place spindle module
 air distribution system, received air from the second
 pick-and-place spindle air distribution port to the
 received spindle of the second pick-and-place spindle
 module;

delivering, by the second pick-and-place spindle electrical
 distribution system, received electricity from the sec-
 ond pick-and-place spindle electrical distribution port
 to the received spindle of the second pick-and-place
 spindle module;

at least partially assembling, by the attached second
 pick-and-place spindle module, the at least one product.

8. The method of assembly of claim 7, the first pick-and-
 place spindle module further including a first module motion
 control chip, the second pick-and-place spindle module
 further including a second module motion control chip, the
 method further comprising:

controlling, using the first module motion control chip,
 speed and acceleration of the first z-axis motor of the
 first pick-and-place spindle module and the first theta
 motor of the first pick-and-place spindle module; and

controlling, using the second module motion control chip,
 speed and acceleration of the second pick-and-place
 spindle first z-axis motor and the second pick-and-place
 spindle first theta motor.

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